THE ECOLOGY OF THE BENTHIC MICROALGAE IN THE SUBLITTORAL ZONE OF THE CHUKCHI SEA NEAR BARROW, ALASKA

A

THESIS

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By

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ABSTRACT

The primary productivity, chlorophyll *a* concentrations and the community composition of the benthic microalgae in the Chukchi Sea near Barrow, Alaska, were determined. Primary productivity experiments were carried out using *in situ* incubation chambers placed in the sediment by SCUBA divers in order to closely simulate natural conditions. Primary productivity ranged from below 0.5 mgC/m^2-hr in the winter when the sampling area was covered with ice to 56.99 mgC/m^2-hr in August. High levels of primary productivity and chlorophyll *a* during the months of July and August can be attributed to the development of a mat of the filamentous diatom *Amphipleura rutilans* on the sediment surface.

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INTRODUCTION

Although much attention has been directed toward taxonomic and ecological studies of the benthic microalgae and the literature on these topics is vast (for a review see Round 1964, 1971), it has been only recently that the primary productivity of this community has received much consideration (Pomeroy 1959; Grøntved 1960, 1962; Wetzel 1964; Hargrave 1968; Steele and Baird 1968; Gargas 1970, 1972; Hickman and Round 1970; Leach 1970; Bunt, Lee and Lee 1972). In many cases the benthic microalgae account for a major portion of the primary productivity of estuarine and nearshore ecosystems. The objectives of this study were 1) to assess the contribution by the benthic microalgae to the total primary productivity of a nearshore area of the Chukchi Sea and 2) to examine the environmental parameters which affect the productivity. To do this, the algal communities of the sea ice and seawater had to be considered because of their possible contribution to the benthos. This is especially true of the ice organisms. Many of the algae which comprise the algal community in the sea ice near Barrow (Horner and Alexander 1972) are pennate diatoms which are typically associated with the benthic habitat. For example, *Amphiprora hyperborea* Grunow and *Nitzschia closterium* W. Smith, which are

often associated with the sediments as well as the planktonic community, are abundant in the ice. *Pleurosigma stuxbergii* Cleve and Grunow, *Pleurosigma angulatum* (Quekett) W. Smith, *Gomphonema exiguum* Kütz. var. *arctica* Grunow and *Gyrosigma fasciola* (Ehrb.) W. Smith as well as several species of *Navicula* and *Nitzschia* are benthic forms that are present in the ice community. The epontic algae, inhabiting the interstitial water of sea ice, reach a maximum primary productivity of about 5 mg C/m^2-hr during May (Clasby, Horner and Alexander In press). This bloom results in the formation of a brown layer on the bottom 2 to 4 cm of the ice and is apparently triggered by increasing light levels due to increased solar radiation and dissipation of snowcover. The bloom ends when the ice begins to melt and extensive drainage of brine pools into the water column occurs. During and after the algal maximum in the ice, these organisms may sink to the bottom and increase the productivity of the benthic biotope.

The benthic microalgae associated with sediments can be divided into two sub-communities: 1) free living motile algae which are usually associated with mud substrates and 2) attached forms which are usually associated with predominantly sandy substrates. These groups have been classified (Round 1964; Hickman and Round 1970) as epipelic and epipsammic algae respectively.

Measuring the productivity of benthic microalgae is complicated by many difficulties due to the heterogenous distribution of the algae, the difficulty in separating the algae from the sediment and the interference with methods of measuring productivity caused by the sediment. Pomeroy (1959) utilized the changes in the dissolved oxygen concentrations in light and dark bell jars pushed into the sediment to measure primary production. Although this method has the advantage of utilizing *in situ* measurements it is tedious, time consuming and it may incorporate errors because respiration in light and dark bottles may be different (Strickland 1960).

Grøntved (1960) was the first person to adopt the ^{14}C technique developed by Steemann Nielsen (1952) for measurement of photosynthetic rates of benthic microalgae. Grøntved divided his samples into epipelic and epipsammic fractions by repeatedly washing the samples and decanting the suspended fractions before incubation. Aliquots of these two fractions were then placed in bottles containing filtered seawater and incubated with ^{14}C. After incubation the samples were filtered and the filters counted on a thin window Geiger counter. Even though the samples were greatly diluted, absorption of the weak β emissions by sediment particles, especially in the sand fraction, was a problem. In order to avoid this, Hickman

(1969) removed the algae from sand grains in the epipsammic fraction by sonification after the incubation was completed and separated the sand and the free algae by washing and decanting. The free living or epipelic algae in his samples were separated from the substrate by placing two layers of lens tissue over sediment which had been spread out in a petri dish. The samples were placed in an incubator overnight and the algae were harvested the following morning by removing the tissues. Eaton and Moss (1966) reported that 87.5% of the algae present in the sediment were trapped in the lens tissues by this method. Since the trapping of algae in the tissue is dependent upon the migration of the algae into the tissue interstices, the time of harvesting is critical (Hickman 1969; Eaton and Moss 1966). It must be accomplished during that period of the diurnal and/or tidal migratory rhythms when the algae have completed their migration to the surface of the substrate. After harvesting, the tissues were placed in incubation bottles and incubated with ^{14}C. Following the incubation the bottles were agitated to remove the algae from the tissues and the tissues removed. The samples were then filtered, and the filter counted with a thin window Geiger counter. One of the advantages of this method is that determinations of primary productivity, chlorophyll *a*, and standing stock can be made from the same sample.

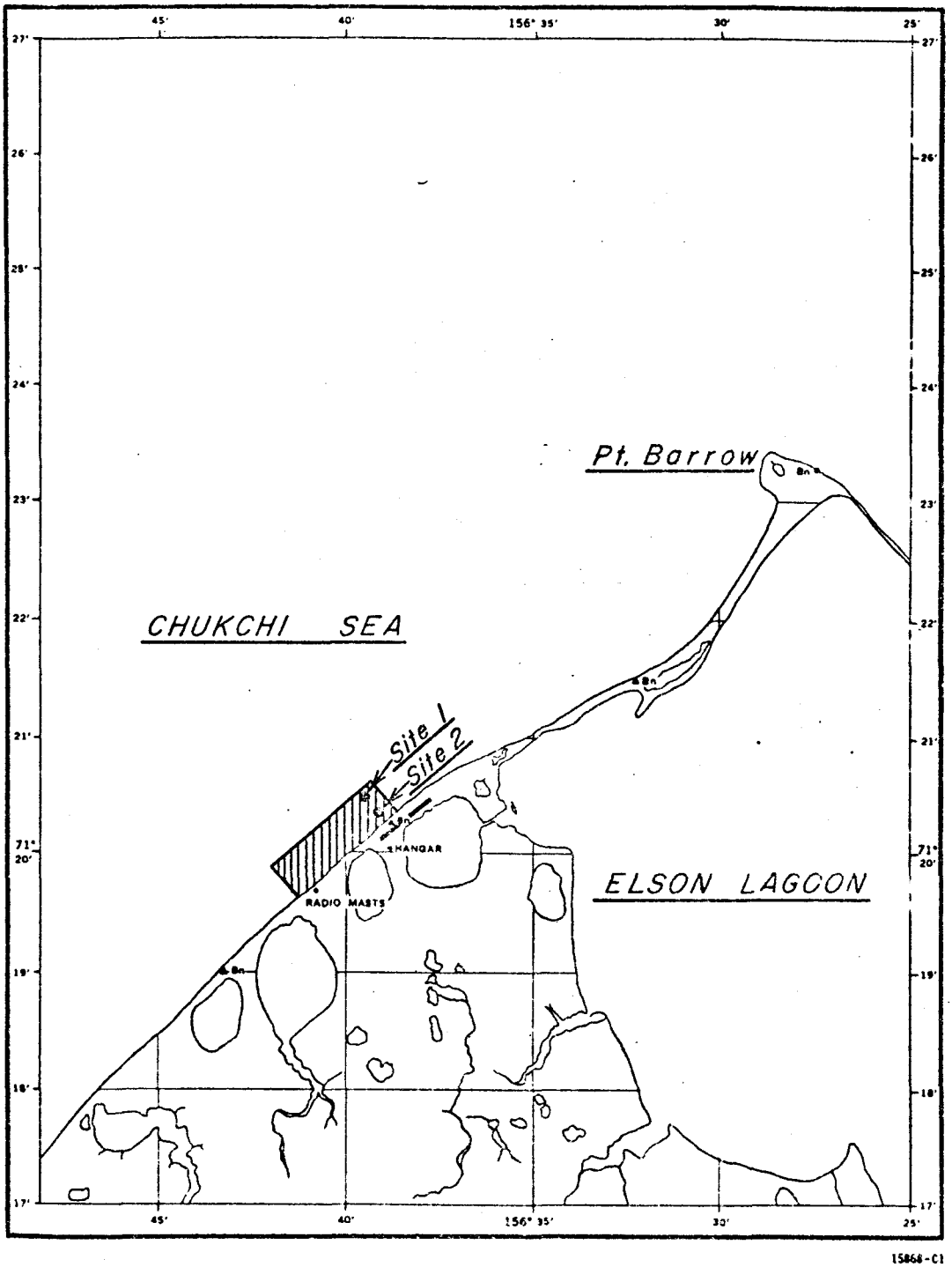
Leach (1970) adapted the ^{14}C technique for use with *in situ* incubation chambers pushed into the sediment of a mudflat. The use of these chambers resulted in minimal disturbance of the algae and the substrate. After incubation the top centimeter of sediment was vacuum dried in a desiccator and a portion of the sample was spread over a planchette and counted on a thin window Geiger counter. Absorption of weak β emissions by sediment particles was corrected for by using a method developed by Baird and Wetzel (1968).

Wetzel (1964) used *in situ* incubation chambers in conjunction with the ^{14}C method and avoided the problem of absorption by combusting his samples with Van Slyke reagents. The uptake of ^{14}C was determined by radioassay of the evolved carbon dioxide in the gas phase. However, this method is slow and tedious. Liquid scintillation counting was used by Stanley (1971) to measure the ^{14}C uptake of benthic microalgae. Samples containing algae and sediments were combusted by wet oxidation and the evolved carbon dioxide was trapped in a phenethylamine scintillation cocktail. This method was about four times faster than Wetzel's method (Stanley 1971) and was highly reproducible.

DESCRIPTION OF THE STUDY AREA

During a preliminary survey made in July and August 1971 samples were taken at different locations selected at random within a kilometer of the shoreline in the Chukchi Sea near the Naval Arctic Research Laboratory, Barrow, Alaska (Fig. 1). Results of chlorophyll *a* analysis of these samples indicated the presence of large scale patchiness in the distribution of benthic microalgae in this area. As a result of this spatial variability temporal changes in biomass could not be discerned (Fig. 2). Therefore, it was decided to concentrate sampling efforts on two sites in an attempt to discover any seasonal changes in biomass and primary productivity that might occur. During the months that the shorefast ice covered the study area (February through mid-July 1972) only one sampling site, site 1, was maintained because there was only one warming hut available for divers. This site was located approximately one kilometer offshore from the hangar at NARL. Diving operations were conducted through a 4 x 5 ft hole cut in the ice. The hole was covered with a plywood board and a layer of snow when not in use so that light conditions below the ice were not substantially altered. The water depth at this station varied from 5 to 6 meters. In July, after the ice was gone, a second sampling area, site 2, was occupied. This area

Figure 1. Location of the sampling sites.



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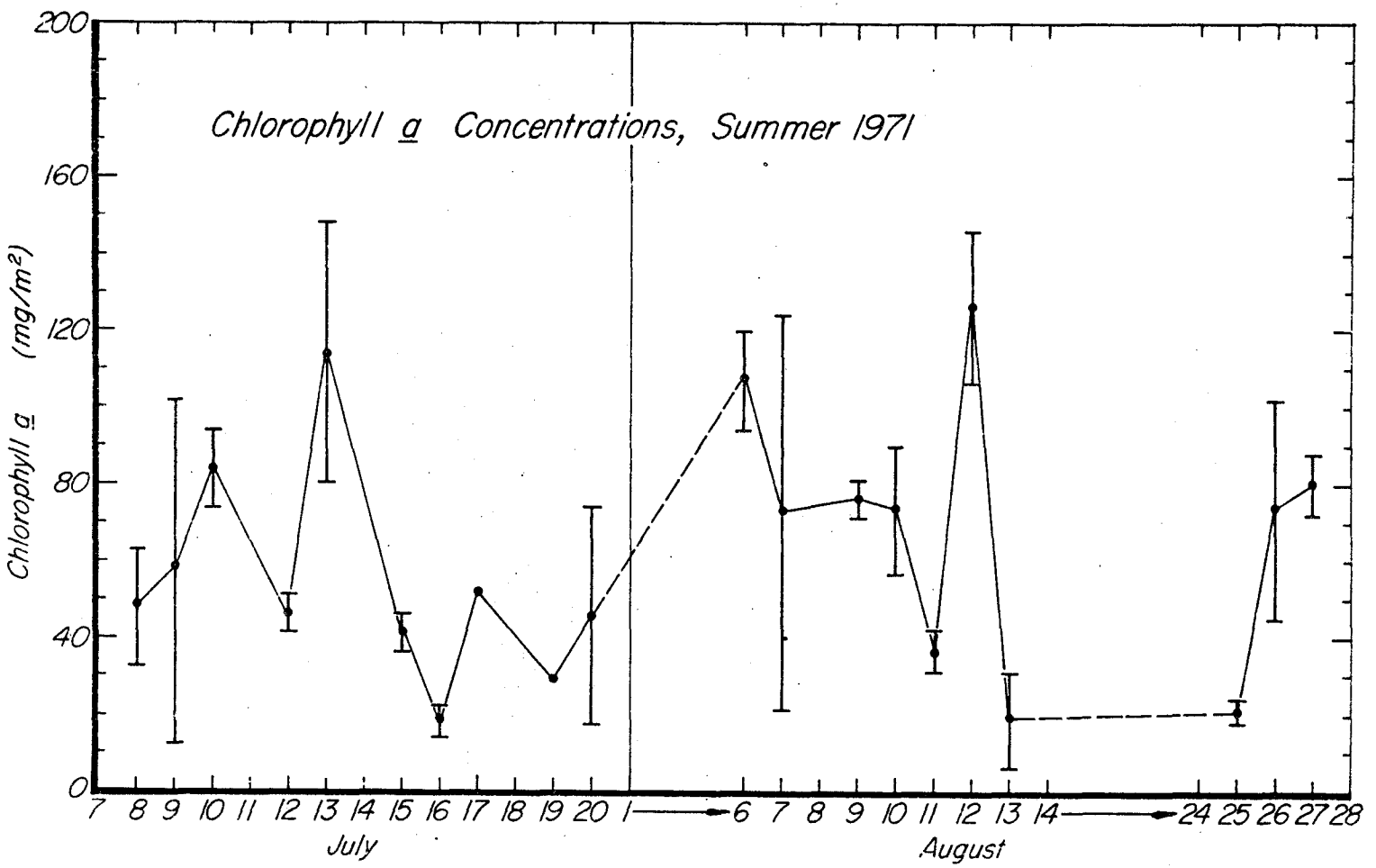
Sampling Area, July - August 1971

Figure 2. Chlorophyll *a* concentrations of samples taken during July and August 1971. Vertical bars represent the standard deviation of replicate cores.


Chlorophyll a Concentrations, Summer 1971
Chlorophyll a (mg/m²)
200
160
120
80
40
0
7 8 9 10 11 12 13 14 15 16 17 18 19 20
July
1 6 7 8 9 10 11 12 13 14 24 25 26 27 28
August

was located about 100 m offshore from the hangar in water about 5 m deep (Fig. 1).

METHODS

3.1. Primary Productivity

Several methods for determining the rate of photosynthesis were tested before a method was selected which was suitable for both the environmental conditions at Barrow and the objectives of this study. Initially, I attempted to use the method developed by Hickman (1969) which utilized lens tissues to trap and separate algae from the sediment. However, I felt that applying the harvesting efficiency of lens tissue reported by Eaton and Moss (1968) to my study might lead to erroneous results. The efficiency that they reported was determined for benthic microalgae from a freshwater environment (Abbot's Pond, Somerset, England) and they utilized a brand of lens tissue which was different from the brand (Kodak Lens Cleaning Tissue) used in my study. In order to determine the actual percentage of algae harvested by the Kodak tissues equal fractions of the sediment in the petri dishes were taken from the area of the petri dishes which had been covered by the lens tissues and from the area which was left uncovered. These fractions were suspended in 500 ml of distilled water and aliquots were then counted on an inverted microscope. Due to the large amount of sediment in the samples counting was very difficult and

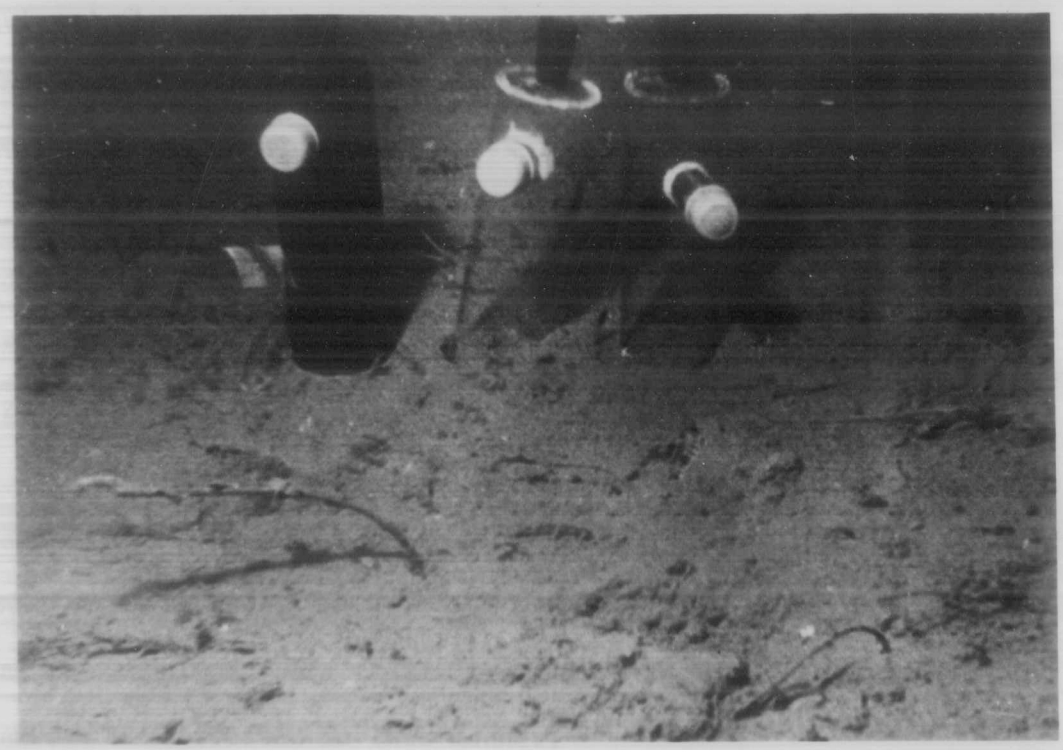
reproducible results could not be obtained. In addition, benthic algae often exhibit marked diurnal and/or tidal rhythms (Round and Eaton 1966; Round and Palmer 1966; Palmer and Round 1967). However, it was not known to what extent the benthic microflora at Barrow would exhibit such rhythms. Therefore, an accurate determination of their migratory rhythms would have been necessary to determine the optimum time to harvest the algae. For these reasons the use of Hickman's (1969) method was abandoned.

Subsequently, a method similar to that used by Steele and Baird (1968) was selected for samples which were taken in areas where the substrate was predominantly sandy. In samples taken from areas that contained primarily silt and clay sediments the methods used were either an adaptation of that used by Leach (1970), or Grøntved's (1960) method for measuring the productivity of the mud fraction. These methods were discontinued because the absorption of weak β radiation by the sediments reduced the counting efficiencies to such low levels that reproducible results could not be obtained.

Finally, in 1972 a method similar to that described by Stanley (1971) was adopted to measure primary productivity. Incubation chambers (Fig. 3a) were constructed by closing plexiglass cylinders (3.4 cm i.d.) at one end with a plexiglass sheet which had a small hole drilled in it to accept a No. 00 rubber stopper. A sidearm

Figure 3a. Plexiglass incubation chambers.

Figure 3b. Injecting ^{14}C into plexiglass incubation chambers.



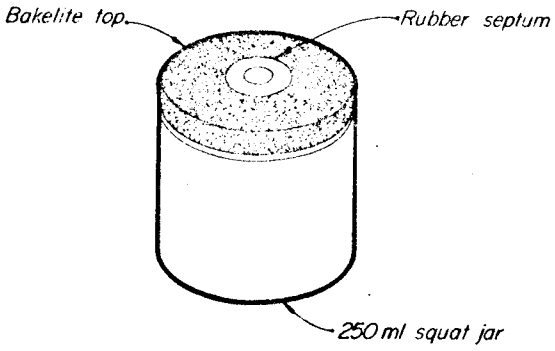
equipped with a rubber sleeve-type serum bottle stopper was placed near the top of the cylinder. The bottom of the cylinder was beveled on the outside to minimize disturbance of the sediment during placement of the chambers. The chambers were placed in the sediment by SCUBA divers up to a mark scribed on the cylinders so that 100 ml of water were enclosed in the incubation chamber. A rubber stopper was inserted in the top of the chamber and 5 µCi of $NaH^{14}CO_3$ were injected into the chamber with a syringe (Fig. 3b). The chambers were then pressed further into the sediment to insure penetration of the label into the sediment. Leach (1970) reported that the label was detected in the 1-2 mm layer when incubation chambers were treated in this manner.

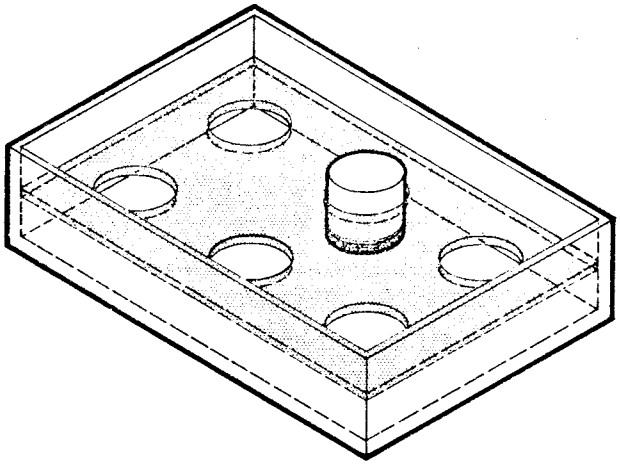
Following the breakup of the shorefast ice that covered the study area until mid-July an algal mat of the filamentous diatom, *Amphipleura rutilans* (Trent.) Cleve developed covering the sediment. It was impossible to use the plexiglass incubation chambers while this layer was present because the edges of the chambers, even when beveled to a sharp edge, would not cut through the tough filaments. As the chambers were inserted the layer of filamentous algae was merely pushed under the sediment surface. In order to circumvent this problem, a new method of sampling had to be devised. A sharpened metal spatula was inserted under the algal mat and small cores

were cut with a number eight cork borer (1.6 cm i.d.) using the spatula as a base to facilitate cutting the filaments. These cores were transferred to 250 ml squat jars and covered with bakelite caps fitted with a septum. The samples were inoculated with 5 μCi of $NaH^{14}CO_3$, inverted slowly and placed in a plexiglass holding box which was left lying on the sediment during the incubation period (Fig. 4). When the jars were inverted the core settled to rest on the top with the filament side up because the denser layer of compacted mud present beneath the algal mat inverted the core as it fell.

One dark and three light incubation chambers were used for each station. Samples were usually incubated for five hours between 0900 and 1400. After incubation the algae were killed with one drop of concentrated H_3PO_4 and the samples were transported to the laboratory. The supernatant water was drawn off and the top centimeter of the core was transferred to a 50 ml centrifuge tube. Previous investigations of light penetration in sands (Taylor and Palmer 1963) and in silts and fine sands (Perkins 1963; Fenchel and Straarup 1971) have shown 1% or less reached a depth of 3 mm. Measurement of light penetration through the *Amphipleura rutilans* mat with a Sekonic S light meter (Sekonic Co. Ltd., Tokyo, Japan) showed that the mat reduced light intensity from 22,000 lux at the surface to undetectable

Figure 4. Incubation chamber and plexiglass holding box used for primary productivity determinations when the *Amphipleura rutilans* algal mat was present.



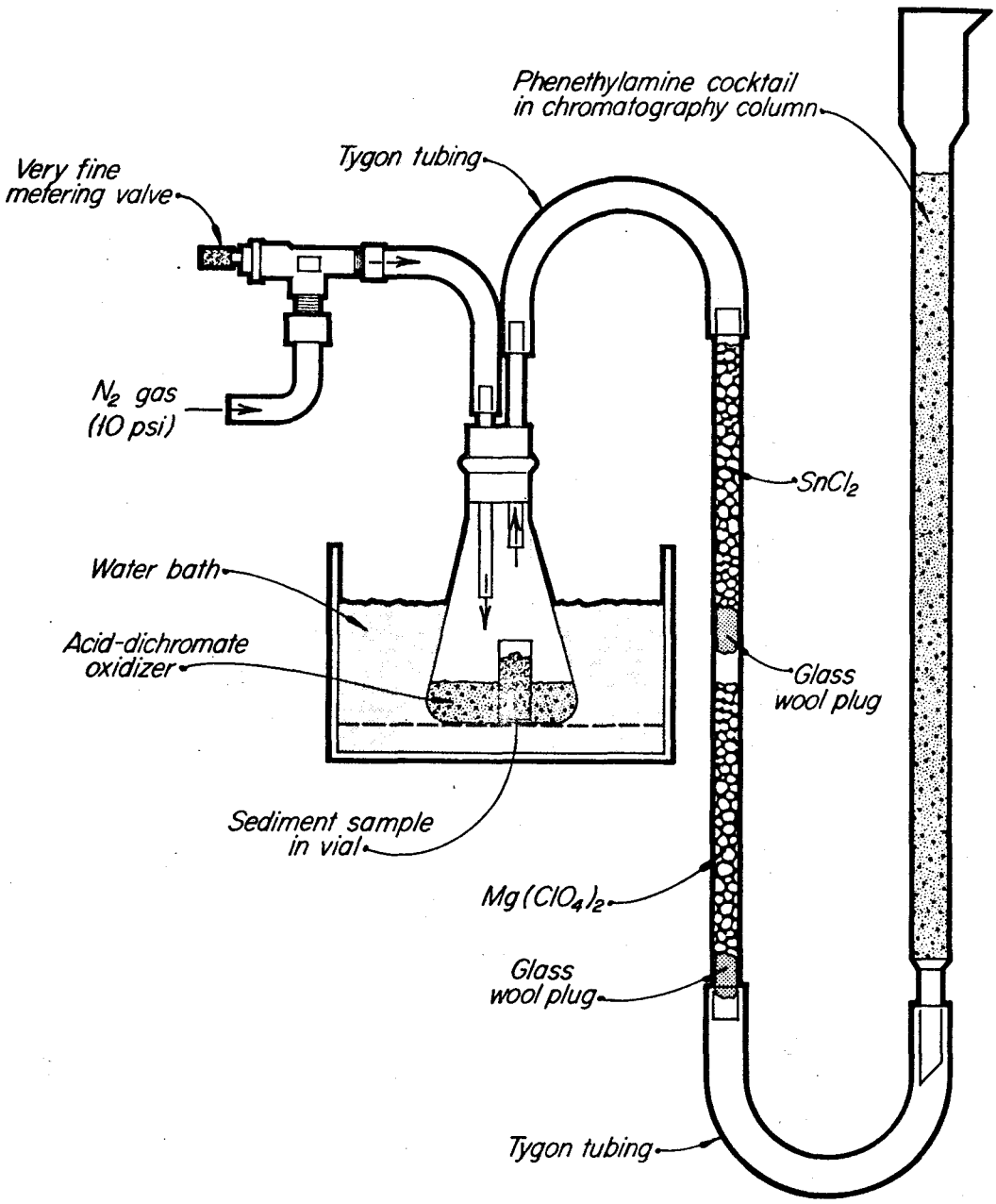


Clear Plexiglass Incubation Box

levels beneath it. After removal from the incubation chamber each sample was washed twice with 0.005N HCl. After each washing the sample was centrifuged for 10 minutes at 2000 g and the supernatant liquid filtered thru a Whatman GF/C glass fiber filter to insure that no algae were lost. Next, the samples were transferred to a combustion vial using a spatula. The centrifuge tube was then washed thoroughly with 0.005N HCl and the wash liquid filtered through the glass fiber filter. The filter was also placed in the combustion vial and the samples were frozen and stored until the combustion could be carried out.

The samples were oxidized in a combustion apparatus designed by Stanley (1971). This apparatus (Fig. 5) consisted of a chain of glassware and tygon tubing flushed with N_2 gas. Nitrogen, which was introduced into the system at 10 psi, flowed thru a drying column packed with Ascarite and into a gas manifold which divided it into four separate flows. Each flow led into a very fine metering valve (Nupro, 1SA, Nupro Co., Cleveland, Ohio) which was connected by tygon tubing to a 125 ml wide mouth erlenmeyer flask. The outflow of the flask was connected to a glass column which contained anhydrous $SnCl_2$, a halogen absorber, and anhydrous $Mg(ClO_4)_2$, a drying agent. This column was connected to a chromatography column, 600 x 10 mm, fitted with a fritted disk at the bottom. The column was filled

Figure 5. Schematic diagram of ^{14}C oxidation apparatus (from Stanley 1971)


Phenethylamine cocktail
in chromatography column
Tygon tubing
Very fine
metering valve
N_2 gas
(10 psi)
$SnCl_2$
Water bath
Acid-dichromate
oxidizer
Glass
wool plug
Sediment sample
in vial
$Mg(ClO_4)_2$
Glass
wool plug
Tygon tubing

with 40 ml of a scintillation cocktail (Woeller 1961) which trapped the CO_2 evolved from the combustion as it bubbled through the solution (Table 1).

Table 1. Composition of the liquid scintillation cocktail

Phenethylamine	540 ml
Absolute methanol	540 ml
Toluene	920 ml
Omnifluor*	8 g

*New England Nuclear Corp., Boston, Mass.

Samples were combusted four at a time in this apparatus. Vials containing the samples were placed upright in the erlenmeyer flasks which were filled with 50 ml of potassium dichromate-sulfuric acid oxidant (Table 2).

Table 2. Composition of the potassium dichromate-sulfuric acid oxidant

Potassium dichromate	50 g
Distilled water	200 ml
Conc. sulfuric acid	

The potassium dichromate is dissolved in the distilled water and the mixture brought up to 1 ℓ with concentrated sulfuric acid.

The rubber stoppers were wetted to insure a good seal and put in the combustion flasks. The nitrogen flow was started and allowed to purge the system and then 40 ml of the phenethylamine cocktail were added to the chromatographic columns. The flow rates were adjusted with the very fine metering valves until they were equal in all four chromatography tubes. The combustion was started by swirling the flasks until the vials tipped over exposing the samples to the dichromate-sulfuric acid solution. The flasks were then placed in a boiling water bath. The combustion was carried out for 90 minutes and the vials were agitated at frequent intervals. Following combustion the cocktail was poured into two 20 ml scintillation vials and the column was rinsed with 20 ml of phenethylamine which were added through the top and collected in a scintillation vial placed under the column. This rinse was necessary to remove any activity remaining on the walls of the column and to remove the phenethylamine-carbamate which tended to precipitate on the fritted disk.

The samples were counted on a Nuclear Chicago Model 6848 liquid scintillation counter (Nuclear Chicago, Des Plaines, Ill.). Quenching was corrected for by using the external standard method. A series of eight quenched standards were made up in the phenethylamine cocktail using carbon tetrachloride as a quenching agent. A quenched standard curve was plotted by determining the external standard ratio (ESR)

and the efficiency (EFF) for each quenched standard. Figure 6 shows a typical quenched standard curve. The counting efficiency of unknown samples can be determined from this curve and the absolute disintegrations per minute calculated using the following equation:

$$dpm = \frac{cpm_s - cpm_{bkg}}{EFF}$$

where

cpm_s = counts per minute, sample

cpm_{bkg} = counts per minute, background

EFF = efficiency

Primary productivity was determined by using the following equation:

$$mg\ C/m^2\text{-}hr = \frac{(R_s - R_b)(W)(1.06)}{(R_a)(A)(N)}$$

where

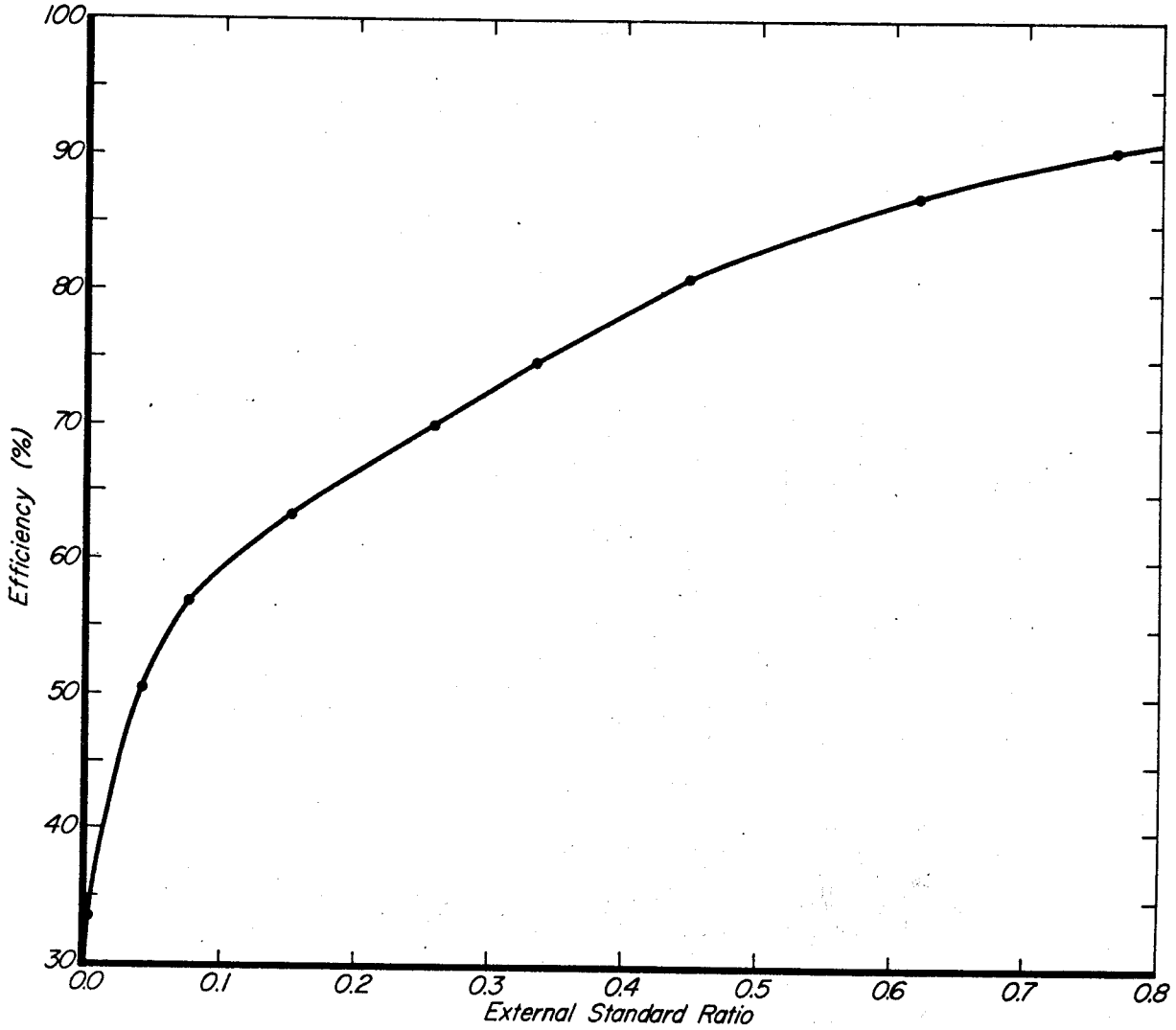
R_s = net dpm of each light sample (the sum of the dpm from each vial making up the light sample)

R_b = net dpm of the dark blank

R_a = activity added (in dpm)

W = mg of inorganic carbon per sample (mg C/100 ml)

Figure 6. Counting efficiency vs. external standard ratio for quenched standards.


100
90
80
70
60
50
40
30
Efficiency (%)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
External Standard Ratio

A = sample area (in m^2)

N = incubation time (in hours)

1.06 = a factor which corrects for the slower rate of utilization of ^{14}C than ^{12}C (Strickland 1960)

The carbonate alkalinity was determined by the method of Strickland and Parsons (1968). Alkalinity samples were taken from the supernatant water of the sediment cores. This might be a source of error in that the algae may utilize the CO_2 in the interstitial water as a source of CO_2. The ΣCO_2 in the interstitial water was always slightly higher than in the water column above the sediment (Appendix D).

3.2. Chlorophyll *a* and Phaeopigment Concentrations

Samples for chlorophyll *a* and phaeopigment analysis were taken with plexiglass core tubes (4.8 cm i.d.) beveled at the bottom to minimize disturbance of the sediment. The cores were pushed into the sediment to a depth of about 5 cm by SCUBA divers, the upper end was capped with a rubber stopper and the core withdrawn until the bottom of the core could be closed with another rubber stopper. Two replicate cores were taken from each station. The samples were returned to the laboratory where the supernatant water was drawn off and sections 1 cm thick were placed in petri dishes and stored in a freezer. In the summer of 1971 only the top cm of sediment was

analyzed while in 1972 the top four cm of each sample were analyzed. The samples were frozen immediately after they were placed in the petri dishes. Before analysis, the samples were thawed in the dark at room temperature; each sample was well mixed with a spatula and two subsamples (ca. 5 gm) were taken from each core. Each subsample was ground with mortar and pestle for 1 min. in 10 ml of 90% acetone, then washed into a centrifuge tube and the volume brought up to 20 ml. The samples were extracted in the dark at 5C for 16 hours and then centrifuged for 10 min. The samples were transferred to a 5 cm cuvette and extinctions were read at 665 nm and 750 nm in a Beckman DU 2 spectrophotometer. The samples were acidified with 2 drops of 1N HCl, shaken well and their extinctions read again after 1 min. (Lorenzen 1967). Chlorophyll *a* and phaeopigments were calculated by an adaptation of Lorenzen's (1967) equations:

$$\text{mg Chl } a/\text{m}^2 = \frac{A \times K \times (665_o - 665_a) \times V}{L \times A_r \times 1{,}000}$$

$$\text{mg Phaeopigments}/\text{m}^2 = \frac{A \times K \times (R[665_a] - 665_o) \times V}{L \times A_r \times 1{,}000}$$

where

A = absorption coefficient of Chl. *a* = 11.0

K = factor to equate the reduction in absorbancy to initial chlorophyll concentration, 1.7:0.7 or 2.43

665_o = absorbance before acidification (-750_o)

665_a = absorbance after acidification (-750_a)

V = volume of acetone used for extraction in ml

L = path length of the cuvette (5.0 cm)

A_r = area of the core sample ($18.1 \times 10^{-4} m^2$)

R = maximum ratio of 665_o: 665_a in the absence of phaeopigments (1.7).

In order to convert chlorophyll *a* values determined in mg/m^2 to µg/g sediment, it was necessary to determine the weight of the sediment per square meter. To this end sediment samples taken in 4.8 cm i.d. core tubes were sectioned into 1 cm sections and dried to constant weight at 80°C.

3.3. Determination of Community Composition

Core samples were examined with a Zeiss phase contrast microscope shortly after they were collected to determine species present. The number of each species found on the slide was counted and species were categorized as abundant, common or present based on the relative number of that species found. A species was classified as dominant if it was obviously the most numerous species in the sample. At least two slides were examined per sample to insure that a representative

subsample was obtained. The upper centimeter of another core sample (3.4 cm i.d.) was transferred to a 250 ml squat jar and preserved with 10% formalin buffered with sodium acetate. These samples were divided into sand and mud fractions by repeatedly washing the samples with distilled water and decanting the suspended fraction. The mud fraction was diluted to 2 ℓ and the sand fraction was diluted to 1 ℓ. Five ml aliquots were taken from each fraction and settled in counting chambers. These samples were counted with a Zeiss phase contrast inverted microscope (Utermöhl 1931) to determine the relative abundance of the species present. Absolute values of the number of cells/m^2 could not be determined because the amount of sediment in the samples obscured or blocked many of the algae from view. In many of the samples the amount of sediment in the silt-clay range was so great that counting with an inverted microscope was impractical. These samples were examined with the standard phase contrast microscope. Since many of the species could not be identified with cell material present selected samples were cleaned by boiling with dilute HCl and then examined with a phase contrast microscope to identify the cells to species.

3.4. Environmental Parameters

3.4.1. Sediments

The silt-clay fraction was separated from the sand fraction by wet sieving with a Tyler Sieve No. 250 (W. S. Tyler Inc., Mentor,

Ohio) and both fractions were dried to constant weight. A continuous recording settling tube similar to the one constructed by Felix (1969) was used for grain size determinations of the sand fraction. A calibration curve was constructed using artificial glass spheres (3M Co., Minneapolis, Minn.) of various phi sizes which were plotted against settling time. The sorting coefficient, So, was calculated according to Trask (1932).

3.4.2. Nutrients

Nutrient samples were taken from the supernatant water directly above the sediments in cores until May 1972 when they were taken from the interstitial water extracted from the upper four centimeters of the sediment. A sediment squeezer designed by Reeburgh (1967) was used to extract the pore water. NH_4^+, NO_3^-, NO_2^-, $PO_4^{\equiv}$ and SiO_3 were measured using autoanalyzer techniques. In some cases nitrate and nitrite were not analyzed separately and are reported as $NO_3^- + NO_2^-$.

3.4.3. Light Intensity

Light intensity was measured with a Sekonic S underwater light meter (Sekonic Co., Tokyo, Japan) and the results were compared with a Gossen Super Pilot light meter (Kling Photo Co., Woodside, N. Y.) for conversion into lux.

RESULTS

4.1. Primary Productivity

Recovery experiments were run to determine the efficiency of the ^{14}C combustion apparatus. Unlabelled sediment samples were taken with the incubation chambers and the top cm was transferred to combustion vials. One hundred λ of ^{14}C glucose (1 μCi/ml) were added to each of the four vials and the standard samples were combusted and counted by the same technique as the unknown samples. Recovery was 94.9% (90% confidence interval=1.79).

A possible source of error in this method was the loss of labelled CO_2 from the phenethylamine cocktail. Georgi and Laber (1965) reported a 50% decrease in activity in three hours. In order to determine if these losses were occurring, samples of various activities were counted immediately after combustion and recounted after varying time intervals. No losses of activity were observed over a period of 5 days (Figs. 7 and 8).

Initial results from the use of this method yielded extremely high activities in the dark blanks. Their range was from 35,000 to 52,000 dpm in samples which had been treated with 0.4% $HgCl_2$ to kill the algae and washed twice with Millipore filtered seawater to remove ^{14}C precipitated as carbonates. In order to reduce this high dark

Figure 7. ^{14}C activity of phenethylamine liquid scintillation cocktail. Samples which start at the five hour mark were prepared five hours after the first series of samples.

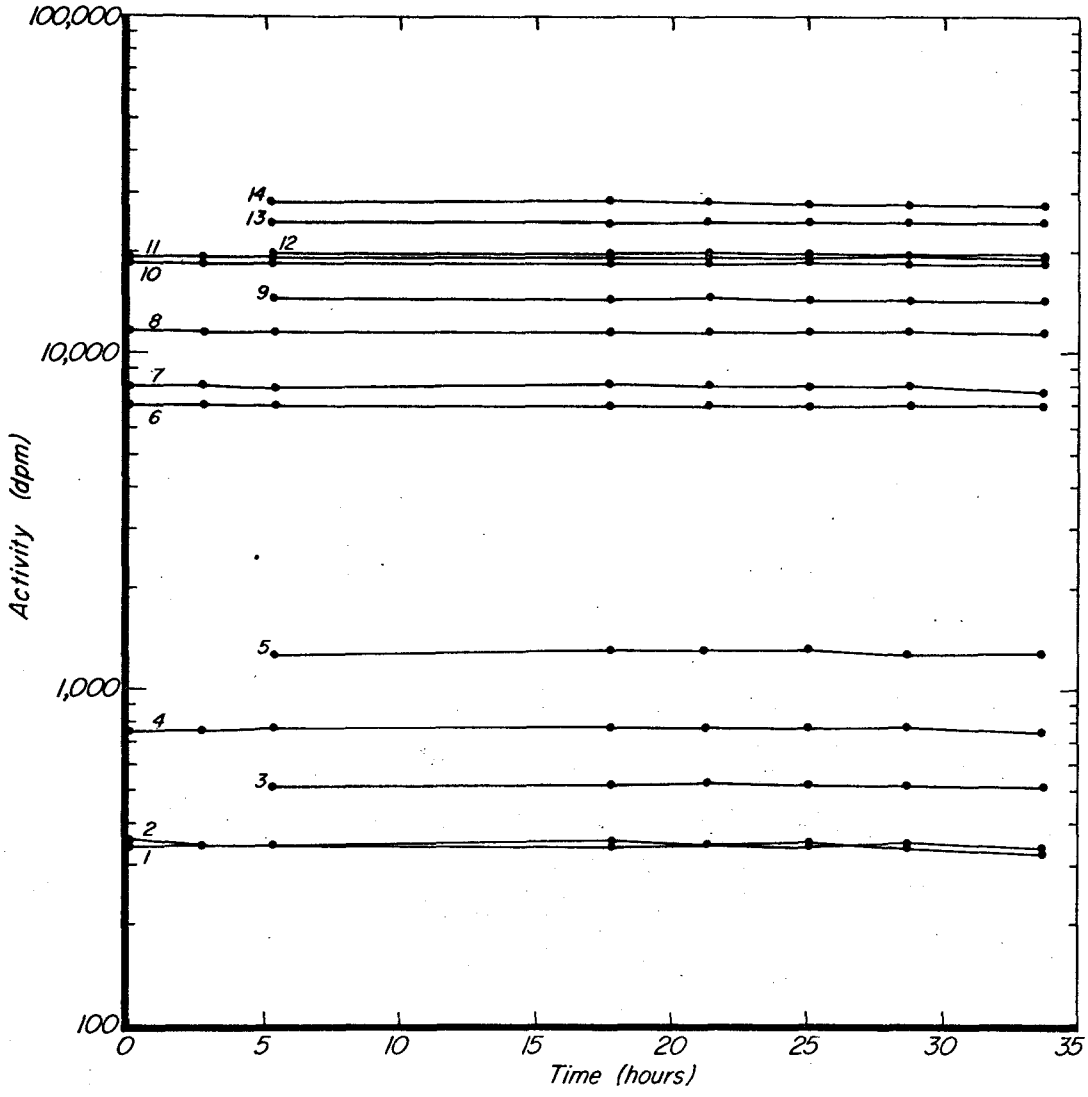
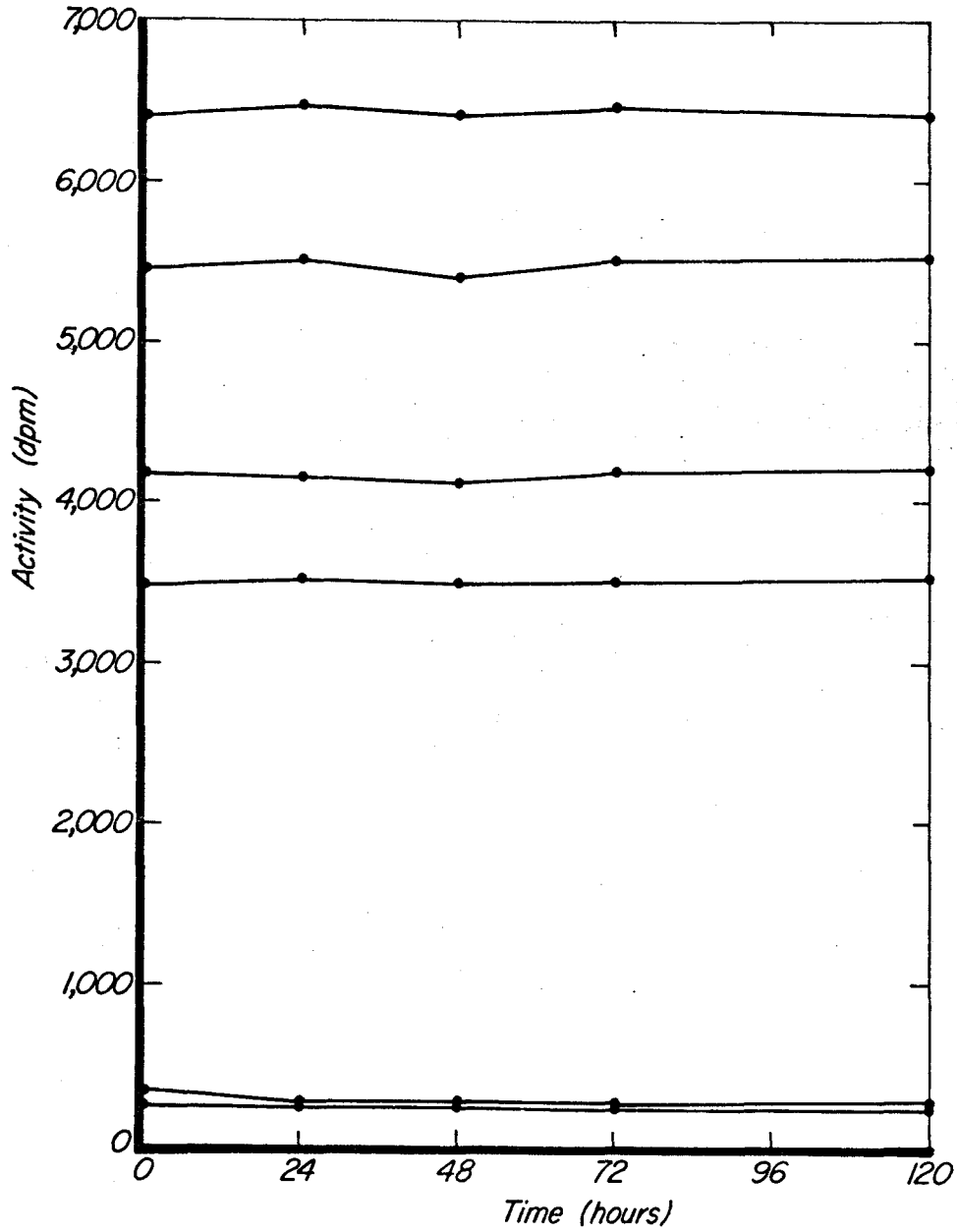

100,000
10,000
1,000
100
Activity (dpm)
0
5
10
15
20
25
30
35
Time (hours)
14
13
12
11
10
9
8
7
6
5
4
3
2
1

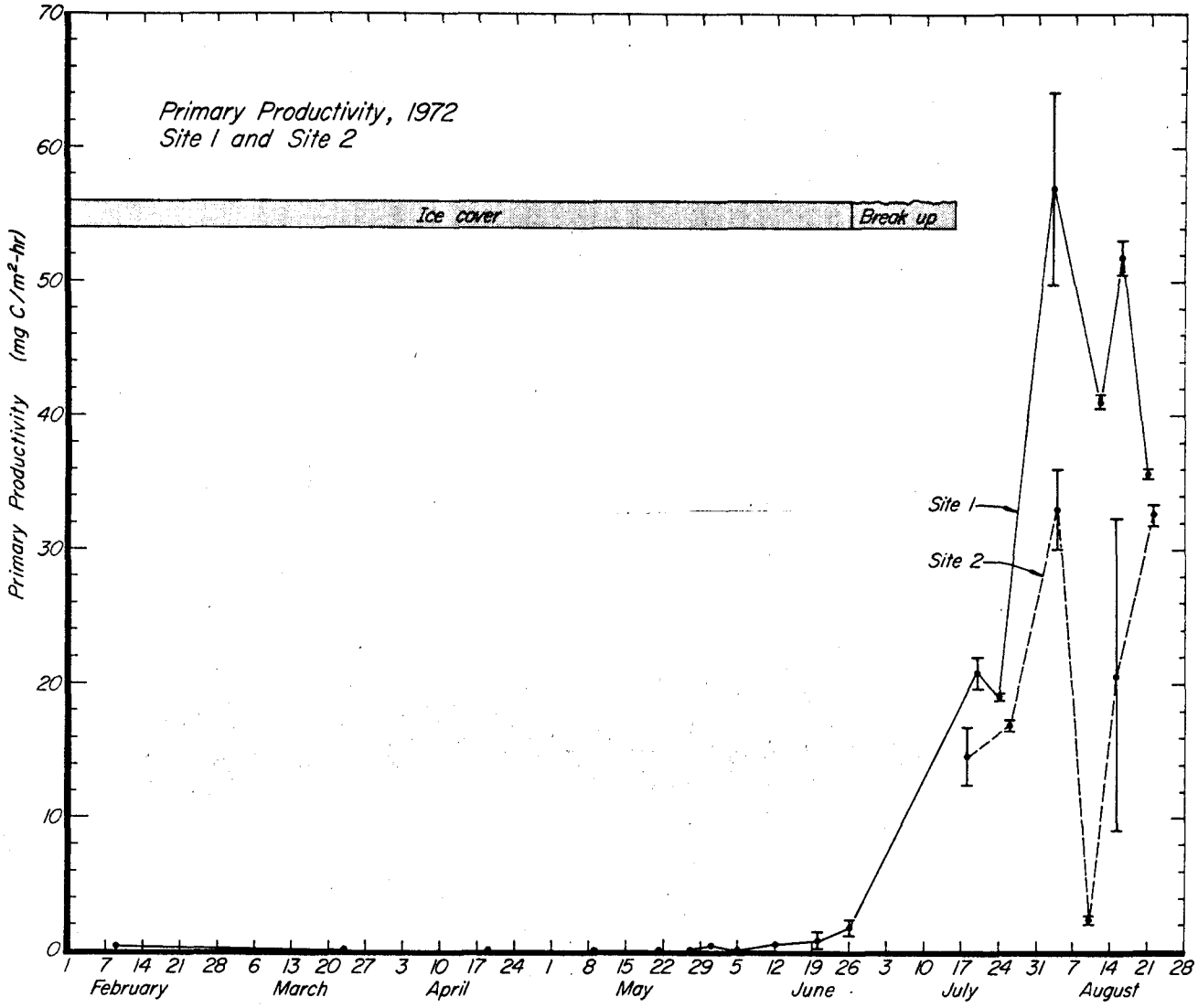
Figure 8. ^{14}C activity of phenethylamine liquid scintillation cocktail.


7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Activity (dpm)
0
24
48
72
96
120
Time (hours)

activity several methods of treating the samples were used. When the samples were washed twice with 0.005N HCl the dark activity was lowered slightly to 10,000 dpm. Fuming the samples with concentrated HCl prior to washing them with filtered seawater produced a similar reduction in dark activity (*ca.* 14,000 dpm). Samples in which the algae were killed after the incubation period with 1 drop of concentrated H_3PO_4, instead of $HgCl_2$, and then washed twice with seawater brought a further reduction in the dark activity to 4,000 dpm. Microscopic examination of algae treated with this concentration of H_3PO_4 (1 drop/100 ml) showed that the acid did not disrupt the cell contents of the algae present. It was found that washing the sample with 0.005N HCl in addition to treatment with H_3PO_4 brought a further reduction in dark activity and this method of treatment was adopted. In order to determine that contamination of the sample during treatment or combustion did not contribute to the dark activity four unlabelled samples were prepared and combusted exactly as the labelled samples were. The activity of all four samples was not above background.

During the period from 9 February until 12 June 1972, primary productivity values (Fig. 9) were very low (<0.5 mg C/m^2-hr). From this point until regular sampling was interrupted while the shorefast ice was breaking up (26 June) the primary productivity values increased

Figure 9. Primary productivity, February - August 1972. Vertical bars are used to represent the standard deviation.


Primary Productivity, 1972
Site I and Site 2
Ice cover
Break up
Primary Productivity (mg C/m²-hr)
Site I
Site 2
0
10
20
30
40
50
60
70
1 7 14 21 28 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28
February
March
April
May
June
July
August

from 0.53 mg C/m^2-hr to 1.86 mg C/m^2-hr. By the time the next station was occupied at site 1 on 19 July the productivity had increased to 20.68 mg C/m^2-hr, an increase of more than an order to magnitude. Primary productivity at site 1 reached a high of 56.99 mg C/m^2-hr on 3 August. The primary productivity at site 2 ranged from 2.35 to 33.04 mg C/m^2-hr and was always lower than that at site 1. On several occasions high standard deviations in the primary productivity values were found.

4.2. Chlorophyll *a* Concentrations

The chlorophyll *a* concentrations in the upper centimeter of sediment ranged from 34.70 to 112.06 mg Chl *a*/m^2 during the months when there was little sunlight (Fig. 10). During late May and early June concentrations of chlorophyll *a* began to increase, reaching 138.85 mg Chl *a*/m^2 by 26 June. On 20 July after the shorefast ice was gone chlorophyll *a* concentrations at site 1 had reached 251.17 mg Chl *a*/m^2. During July and August chlorophyll *a* at site 1 ranged from 249.79 to 321.01 mg Chl *a*/m^2. Chlorophyll *a* concentrations at site 2 were lower than those at site 1 except for one occasion (10 Aug.). Chlorophyll *a* concentration decreased with depth (Fig. 11; Appendix C); a nested analysis of variance indicated that there was a significant difference in chlorophyll concentrations with depth in

Figure 10. Chlorophyll *a* concentrations in the upper 1 cm of sediment, February - August 1972. Vertical bars represent the standard deviation.

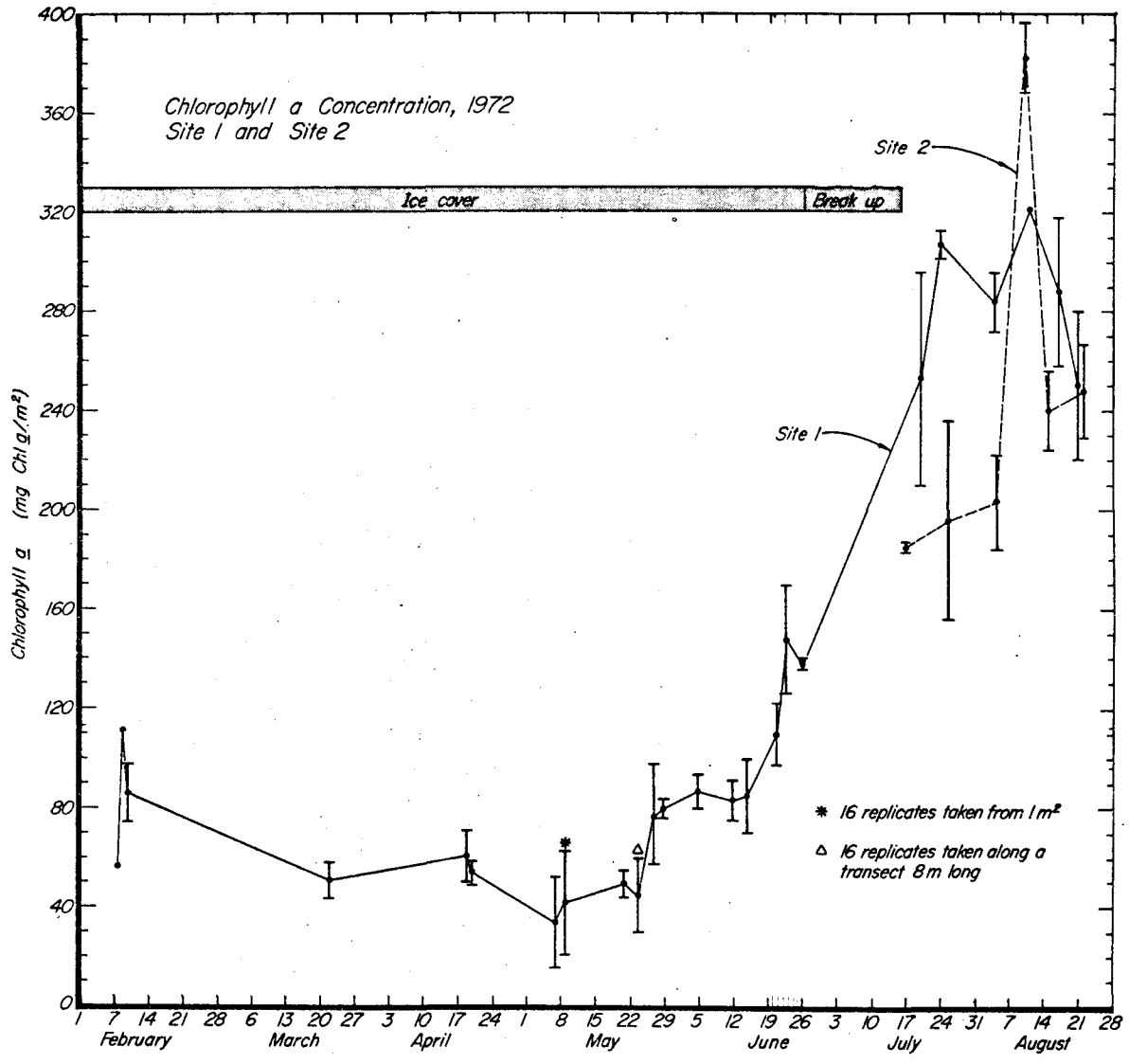
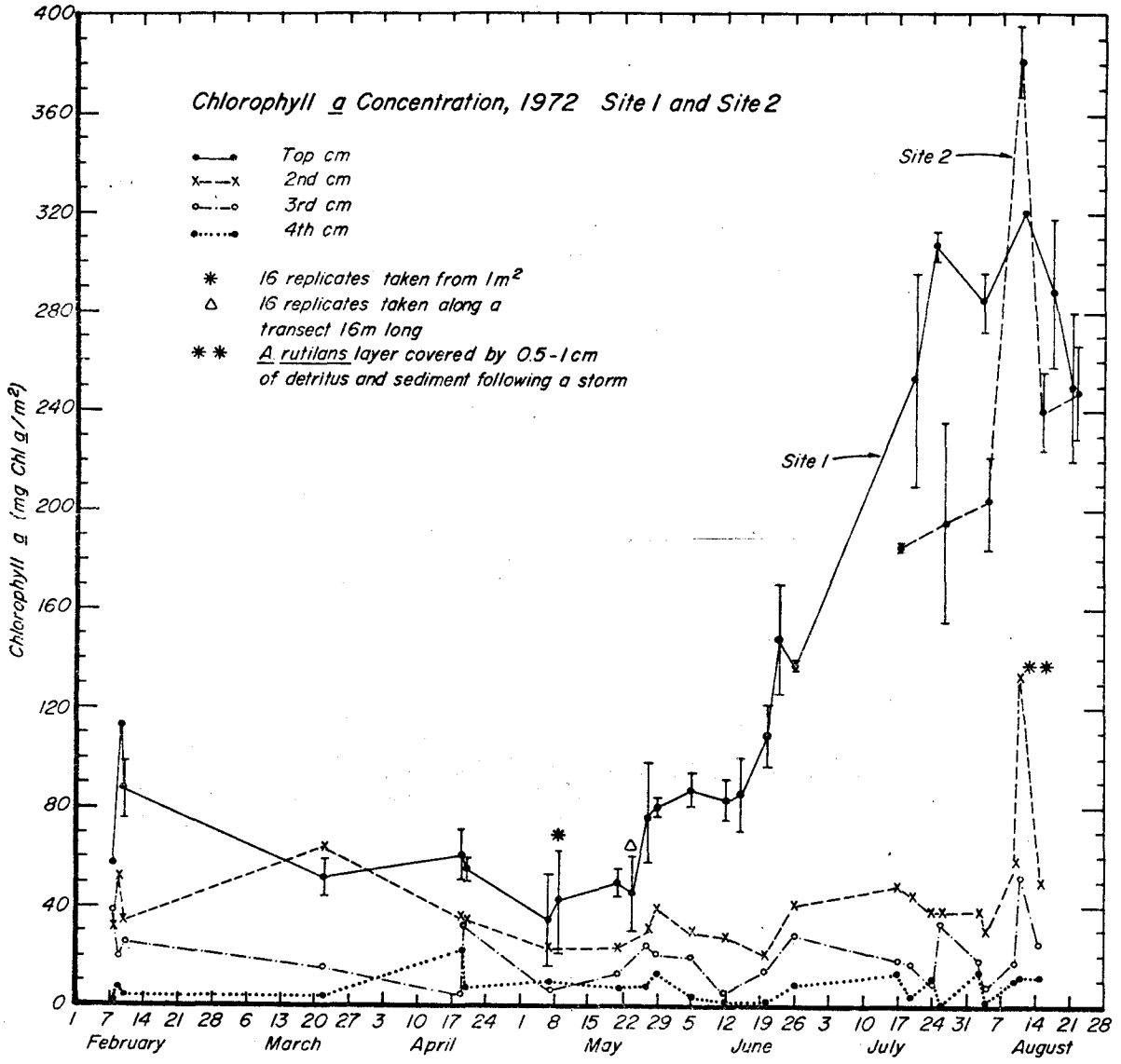

Chlorophyll a Concentration, 1972
Site 1 and Site 2
Ice cover
Break up
Site 2
Site 1
Chlorophyll a (mg Chl a/m²)
* 16 replicates taken from 1 m²
△ 16 replicates taken along a transect 8 m long
0
40
80
120
160
200
240
280
320
360
400
1 7 14 21 28 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28
February
March
April
May
June
July
August

Figure 11. Chlorophyll *a* concentration in the upper 4 cm of sediment, February - August 1972. Vertical bars represent the standard deviation. Data for site 1 and site 2 were pooled in the 2nd through 4th cm.

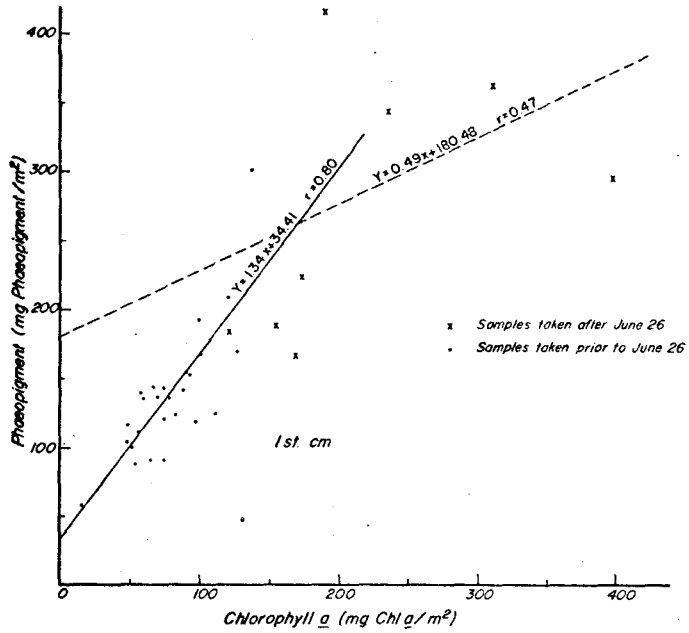

Chlorophyll a Concentration, 1972 Site 1 and Site 2
Top cm
2nd cm
3rd cm
4th cm
16 replicates taken from 1m²
16 replicates taken along a transect 16m long
A. rutilans layer covered by 0.5-1cm of detritus and sediment following a storm
Site 2
Site 1
Chlorophyll a (mg Chl a/m²)
0
40
80
120
160
200
240
280
320
360
400
1 7 14 21 28 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28
February
March
April
May
June
July
August

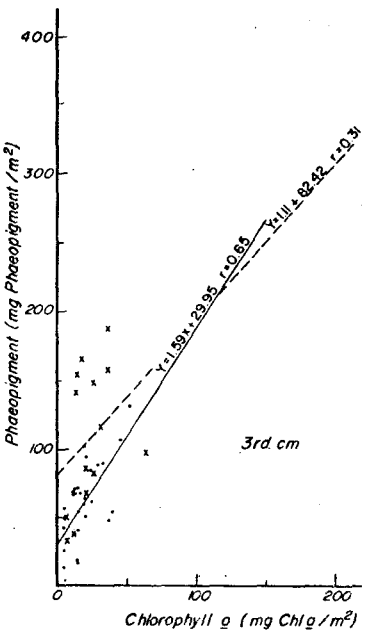
the sample cores ($p<0.05$; Appendix B). The only significant temporal change in chlorophyll concentration occurred in the samples from the upper centimeter ($p<0.05$; Appendix B).

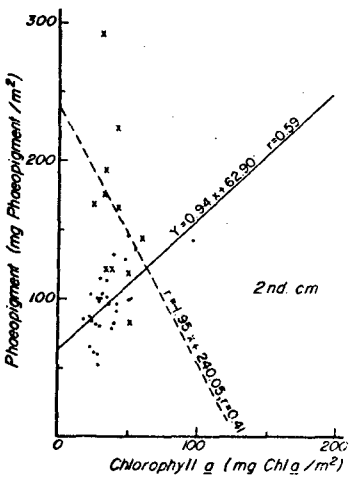
An analysis of variance was also used to determine the subsampling error for all cores. The upper percentage confidence limit for a single subsample is 193 ($P = 0.05$; Appendix B). This level of precision is interpreted such that if one subsample contains 100 mg chlorophyll *a*, then any second subsample removed in a similar manner is expected to contain no more than 193 mg Chl *a* or less than 52 mg Chl *a* unless one chance in twenty has occurred to produce a more deviant value. In contrast, the upper percentage confidence limit for one of the replicate cores taken on the same day was 266 ($P = 0.05$; Appendix B).

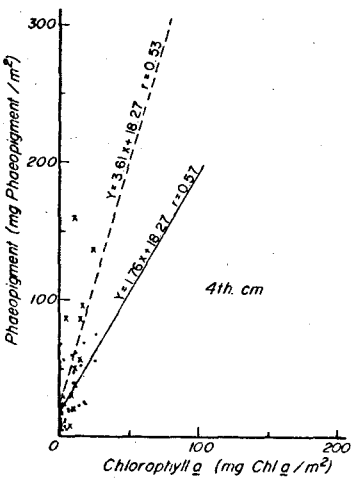
Linear regression analysis was used to compare chlorophyll *a* and phaeopigment concentrations in each of the four centimeters of the sediment samples. There was no correlation in the upper 2 cm ($P>0.05$; Appendix B) between chlorophyll *a* and phaeopigments when compared throughout the season. However, when samples taken after *Amphipleura rutilans* became the dominant species in the community were deleted there was a correlation ($p<0.05$; Appendix B) between these parameters (Fig. 12). The slope of the regression line increases in the third and fourth centimeters, indicating a greater percentage of phaeopigment at these levels.

Figure 12. The relationship between chlorophyll *a* and phaeopigment concentrations for the upper 4 cm of sediment. Regression lines for samples taken prior to 26 June are solid; for samples taken after 26 June, broken.


Phaeopigment (mg Phaeopigment /m²)
Chlorophyll a (mg Chl a/m²)
Y=1.34x+34.41 r=0.80
Y=0.49x+180.48 r=0.47
Samples taken after June 26
Samples taken prior to June 26
1st. cm


Phaeopigment (mg Phaeopigment /m²)
Chlorophyll a (mg Chl a/m²)
Y=1.59x+29.95 r=0.65
Y=111+82.42 r=0.31
3rd. cm


Phaeopigment (mg Phaeopigment /m²)
Chlorophyll a (mg Chl a/m²)
Y=0.94x+62.90 r=0.59
r=1.95x+240.05 r=0.41
2nd. cm


Phaeopigment (mg Phaeopigment /m²)
Chlorophyll a (mg Chl a/m²)
Y=3.61x+16.27 r=0.53
Y=1.75x+18.27 r=0.57
4th. cm

4.3. Description of the Community

The species which comprised the benthic microalgal community during the periods of July-August 1971 and February-August 1972 are listed in Tables 3 and 4. This community is composed of predominantly pennate diatoms. The dominant species during the period from July through August 1971 was *Diploneis smithii* (Bréb.) Cleve. *Diploneis subcincta* (A.S.) Cleve, *Gyrosigma* spp., *Pleurosigma* spp. and *Navicula* spp. were also abundant (Table 3). In 1972 the composition of the benthic microalgal community had changed somewhat. *Diploneis smithii* was no longer the dominant species. From February until July 1972 the community was dominated by *Pleurosigma stuxbergii* and two species resembling *Gyrosigma spencerii* W. Smith and *Pleurosigma longum* Cleve. *Pleurosigma stuxbergii* was very similar to *Pleurosigma longum* and was distinguishable from that species only by the rhomboid shape of the central nodule. The three species *P. stuxbergii*, *P. longum* and *G. spencerii* could only be distinguished by washing the cells with acid to remove the cell contents. In routine examinations and inverted microscope counts of the sediment community these three species were grouped together (Table 4). *Gyrosigma fasciola*, *Gyrosigma tenuissimum* var. *hyperborea* Grunow, *Navicula directa* Cleve (Heimdal 1970) and a species of *Navicula* (Fig. 13) were also common during this period. While the shorefast ice was breaking up (26 June -

Table 3. Benthic Microflora at Barrow, July-August 1971

Abundant

Diploneis smithii (Bréb.) Cleve var. *smithii*
Diploneis subcincta (A.S.) Cleve
Gyrosigma fasciola (Ehrb.) W. Smith
Gyrosigma spencerii W. Smith
Pleurosigma longum Cleve
Pleurosigma stuxbergii Cleve and Grunow
Amphora spp.
Navicula spp.
Nitzschia spp.

Common

Amphiprora hyperborea Grunow
Caloneis brevis Cleve
Melosira sulcata (Ehrb.) Kützing
Nitzschia closterium W. Smith
Nitzschia grunowii Hasle
Nitzschia paradoxa Grunow
Pleurosigma angulatum (Quekett) W. Smith
Amphiprora spp.

Present

Biddulphia aurita (Lyngb.) Brébisson and Godey
Coscinodiscus centralis Ehrenberg
Coscinodiscus radiatus Ehrenberg
Pinnularia quadratarea (A.S.) Cleve
Thalassiosira sp.

Table 4. Benthic microflora at Barrow February - August 1972

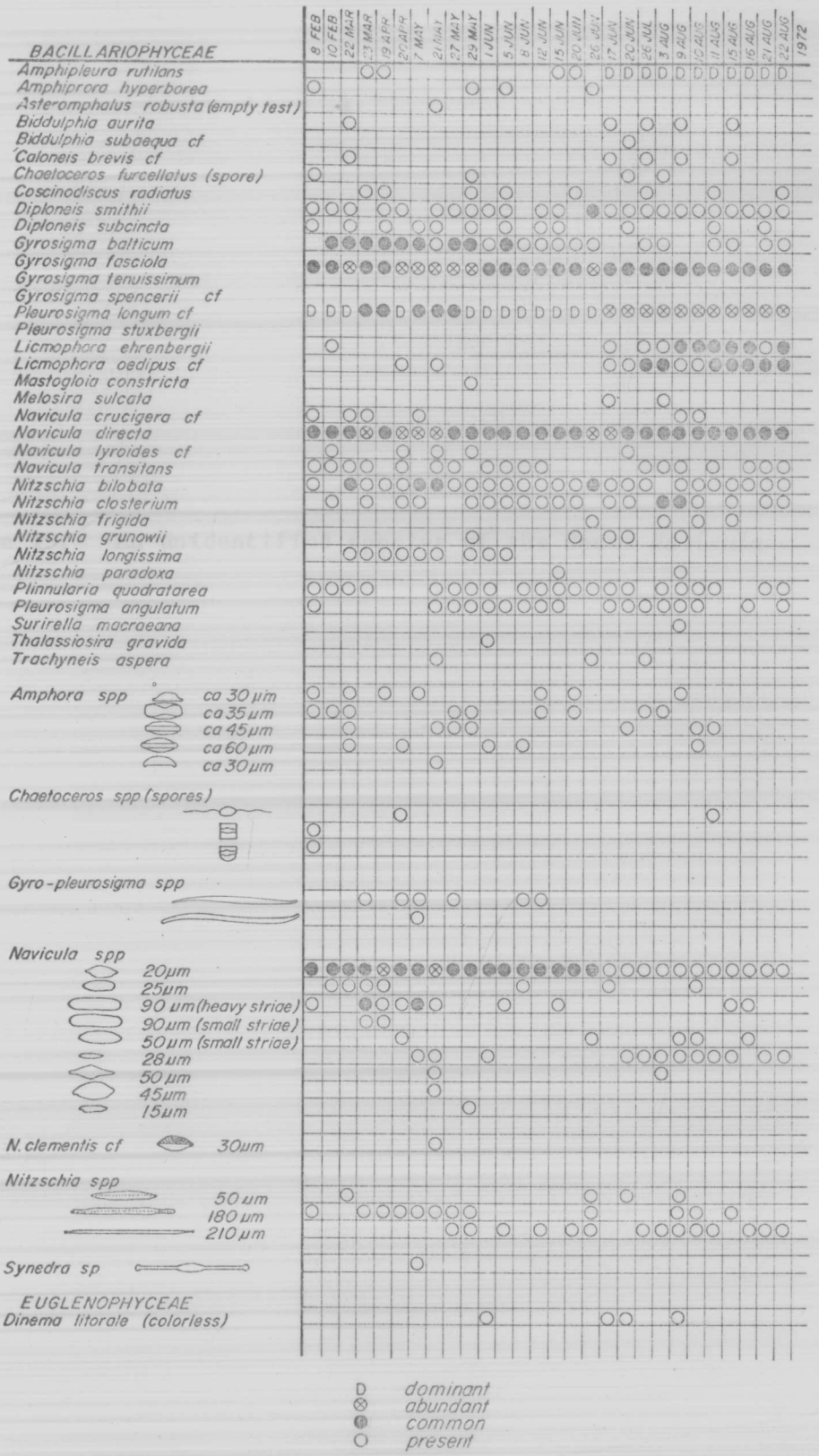
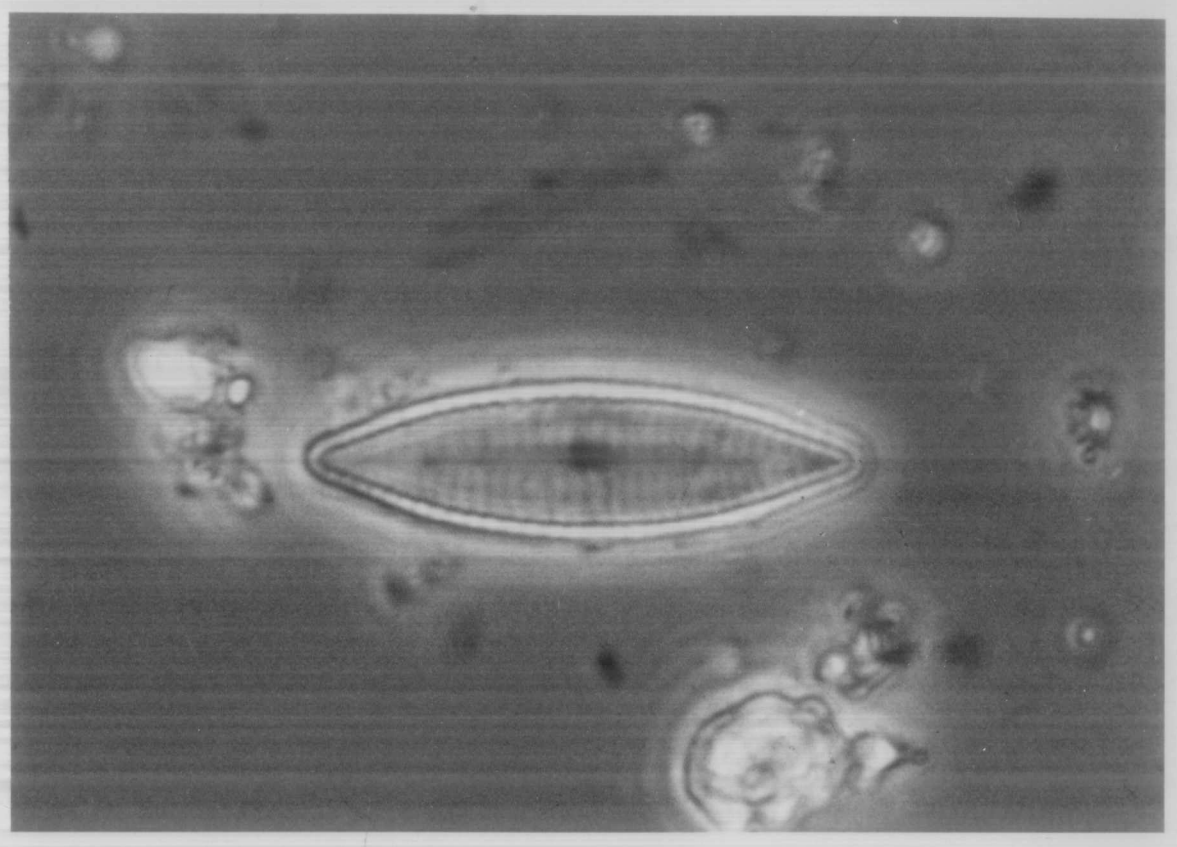

8 FEB
10 FEB
22 MAR
23 MAR
19 APR
26 APR
7 MAY
21 MAY
27 MAY
29 MAY
1 JUN
5 JUN
8 JUN
12 JUN
15 JUN
20 JUN
26 JUN
17 JUN
20 JUN
26 JUL
3 AUG
9 AUG
10 AUG
11 AUG
15 AUG
16 AUG
21 AUG
22 AUG
1972
BACILLARIOPHYCEAE
Amphipleura rutilans
Amphiprora hyperborea
Asteromphalus robusta (empty test)
Biddulphia aurita
Biddulphia subaequa cf
Caloneis brevis cf
Chaetoceros furcellatus (spore)
Coscinodiscus radiatus
Diploneis smithii
Diploneis subcincta
Gyrosigma balticum
Gyrosigma fasciola
Gyrosigma tenuissimum
Gyrosigma spencerii cf
Pleurosigma longum cf
Pleurosigma stuxbergii
Licmophora ehrenbergii
Licmophora oedipus cf
Mastogloia constricta
Melosira sulcata
Navicula crucigera cf
Navicula directa
Navicula lyroides cf
Navicula transitans
Nitzschia bilobata
Nitzschia closterium
Nitzschia frigida
Nitzschia grunowii
Nitzschia longissima
Nitzschia paradoxa
Plinnularia quadratarea
Pleurosigma angulatum
Surirella macraeana
Thalassiosira gravida
Trachyneis aspera
Amphora spp
ca 30 µm
ca 35 µm
ca 45 µm
ca 60 µm
ca 30 µm
Chaetoceros spp (spores)
Gyro-pleurosigma spp
Navicula spp
20µm
25µm
90 µm (heavy striae)
90µm (small striae)
50µm (small striae)
28µm
50µm
45µm
15µm
N. clementis cf
30µm
Nitzschia spp
50 µm
180 µm
210 µm
Synedra sp
EUGLENOPHYCEAE
Dinema litorale (colorless)
D dominant
⊗ abundant
common
○ present

Figure 13. An unidentified species of the Genus *Navicula*



12 July 1972) a mat of the filamentous diatom *Amphipleura rutilans* developed and covered the sediment surface at sites 1 and 2. This species was the dominant member of the benthic community for the remainder of the summer. *Licmophora ehrenbergii* (Kütz.) Grunow and a species resembling *L. oedipus* (Kütz.) Grunow were common as epiphytes on the filaments of *A. rutilans* (Fig. 14). The free living diatoms discussed above were still common both among the filaments and in the sediments below the mat formed by *A. rutilans*. However, one species of *Navicula* (Fig. 13) showed a considerable decline in abundance after the development of the algal layer of *A. rutilans*.

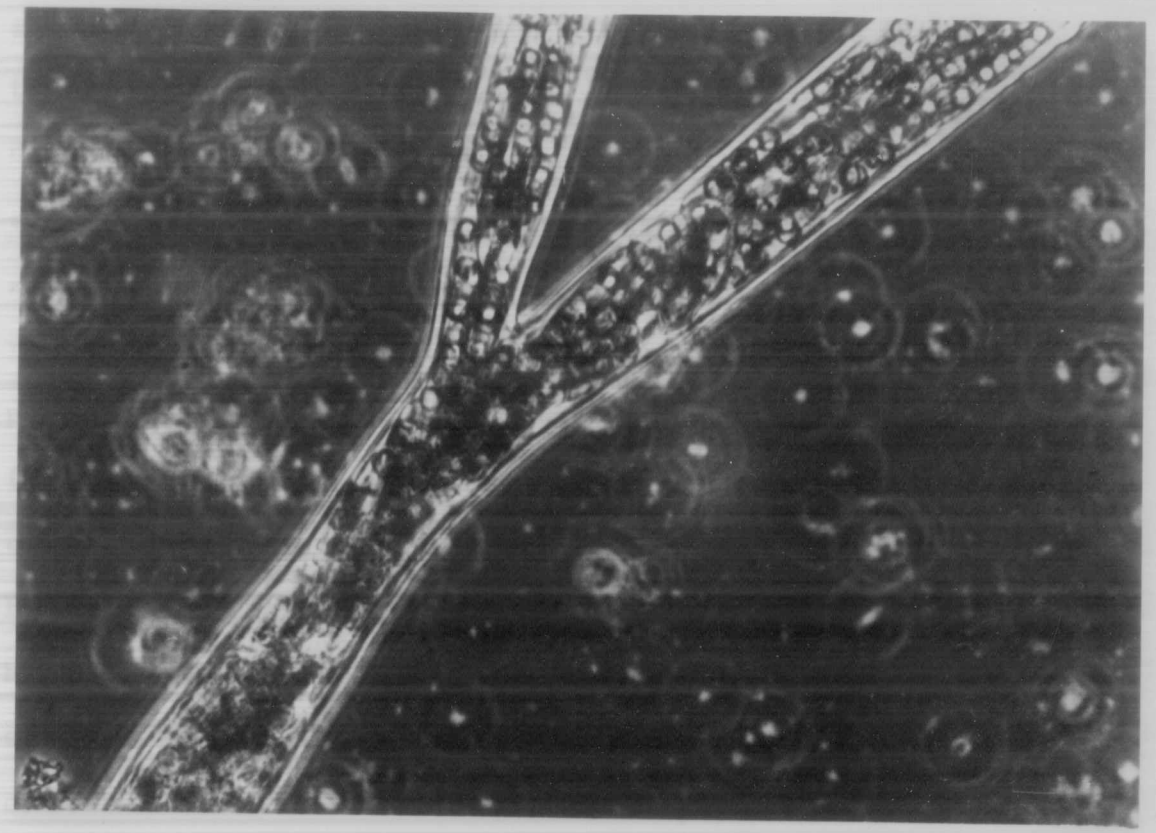
In all of the samples examined epipsammic diatoms attached to sand grains were rarely encountered. All the observed attached diatoms were a small species of *Navicula* (ca. 20 µm) which was also common as a free living form (Fig. 13). The epipsammic algae are an insigificant part of the benthic community at Barrow. This is perhaps because even in predominantly sandy areas the sediment was covered with a thin layer of mud which would greatly reduce light available to attached diatoms below the mud.

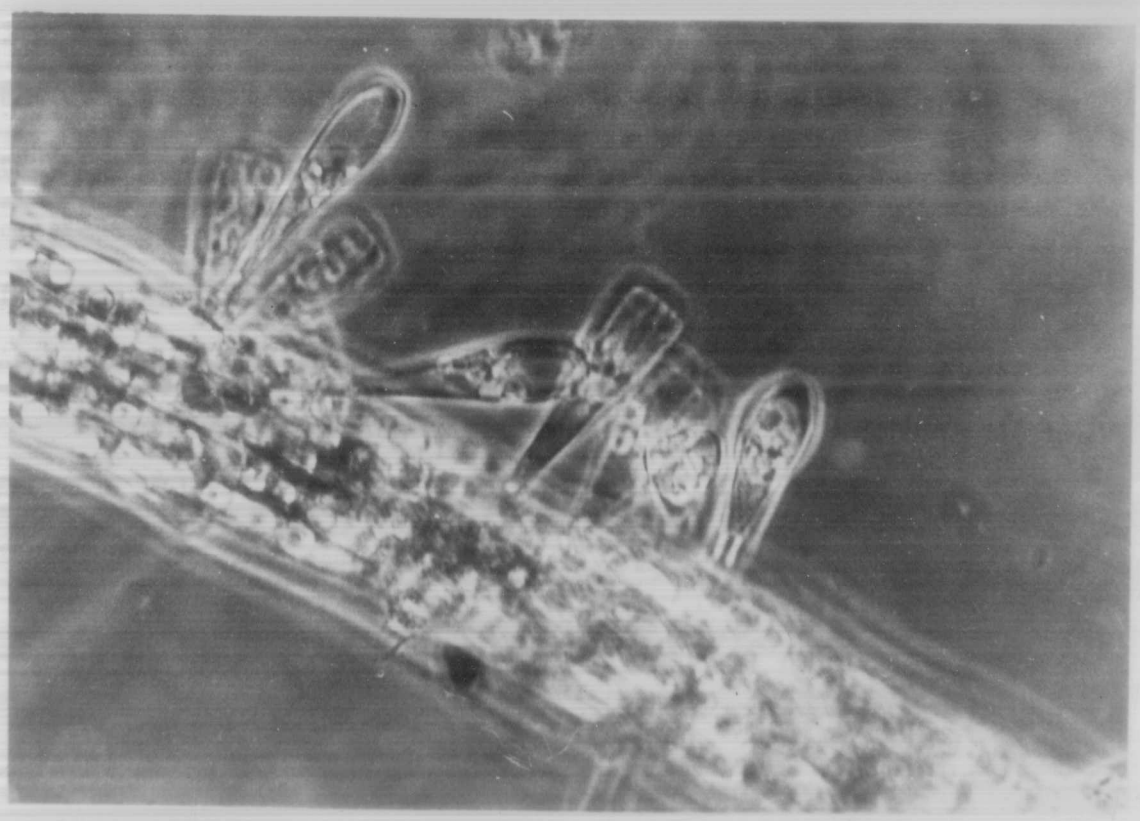
4.4. Environmental Parameters

The upper centimeter of sediment at site 1 and site 2 was composed of mud intermixed with fine and very fine sands [based on the Wentworth scale (Wentworth 1922)]. The sediment composition

Figure 14a. Mucilagenous tubes containing *Amphipleura rutilans*.

Figure 14b. *Licmophora* sp. attached to mucilagenous tubes of *Amphipleura rutilans*.





graded down to predominantly fine and very fine sands in the second through fourth centimeter below the surface. There were no significant differences ($P>0.05$) in the sediment composition in samples of the top centimeter and the top four centimeters between site 1 and site 2. The top centimeter of sediment had a silt-clay content ranging from 13 to 73% by weight ($\bar{X} = 40.7 \pm 16.9\%$) and a median phi size from 3.05 to >4.00. These sediments were well sorted ($So = 1.4 \pm 0.8$). It appears that there was a change in the sediment composition at site 1 during late April and early May 1972. From February to 19 April the median phi size was greater than 4.0 in all but one sample ($Md\phi = 3.3$) and from May to August the median phi size had dropped to 3.53 ± 0.30. Samples of the top four centimeters of sediment at sites 1 and 2 had a median phi size from 2.97 to 3.95 ($\bar{X} = 3.26 \pm 0.23$) and the percent of silt-clay ranged from 8 to 49% ($\bar{X} = 26.3 \pm 10.3$). A one way analysis of variance indicated that the median phi size was significantly greater in the top centimeter than in the top four centimeters ($p<0.05$). Cumulative frequency graphs of phi size for sediment samples are shown in Appendix A.

Seasonal changes in salinity, nutrients and light intensity are shown in Figures 15 and 16. Light intensity at the sediment-water interface was not measured until early May 1972. Light intensity at

Figure 15. Light intensity at the sediment-water interface.

(2) represents measurements taken at site 2.

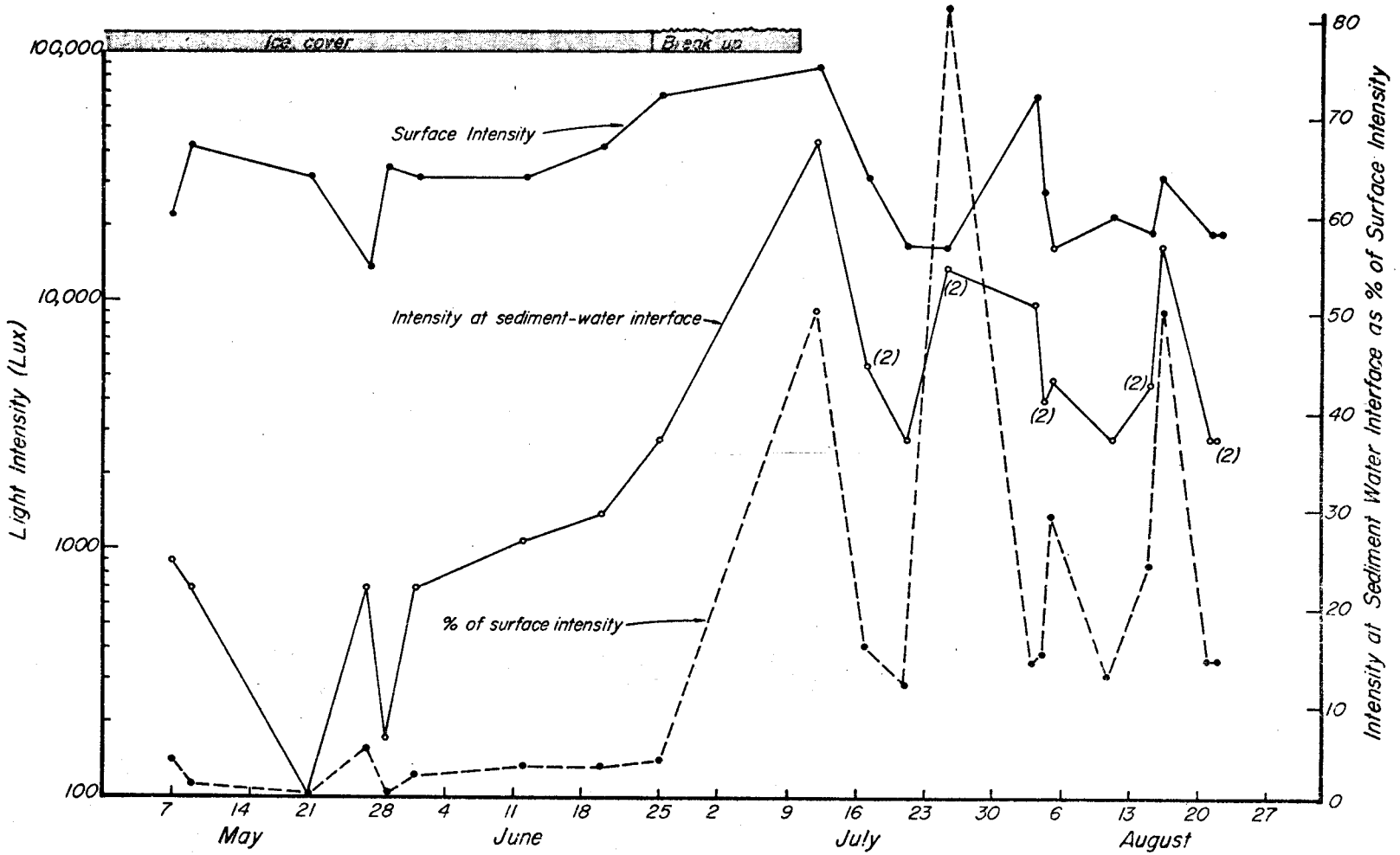
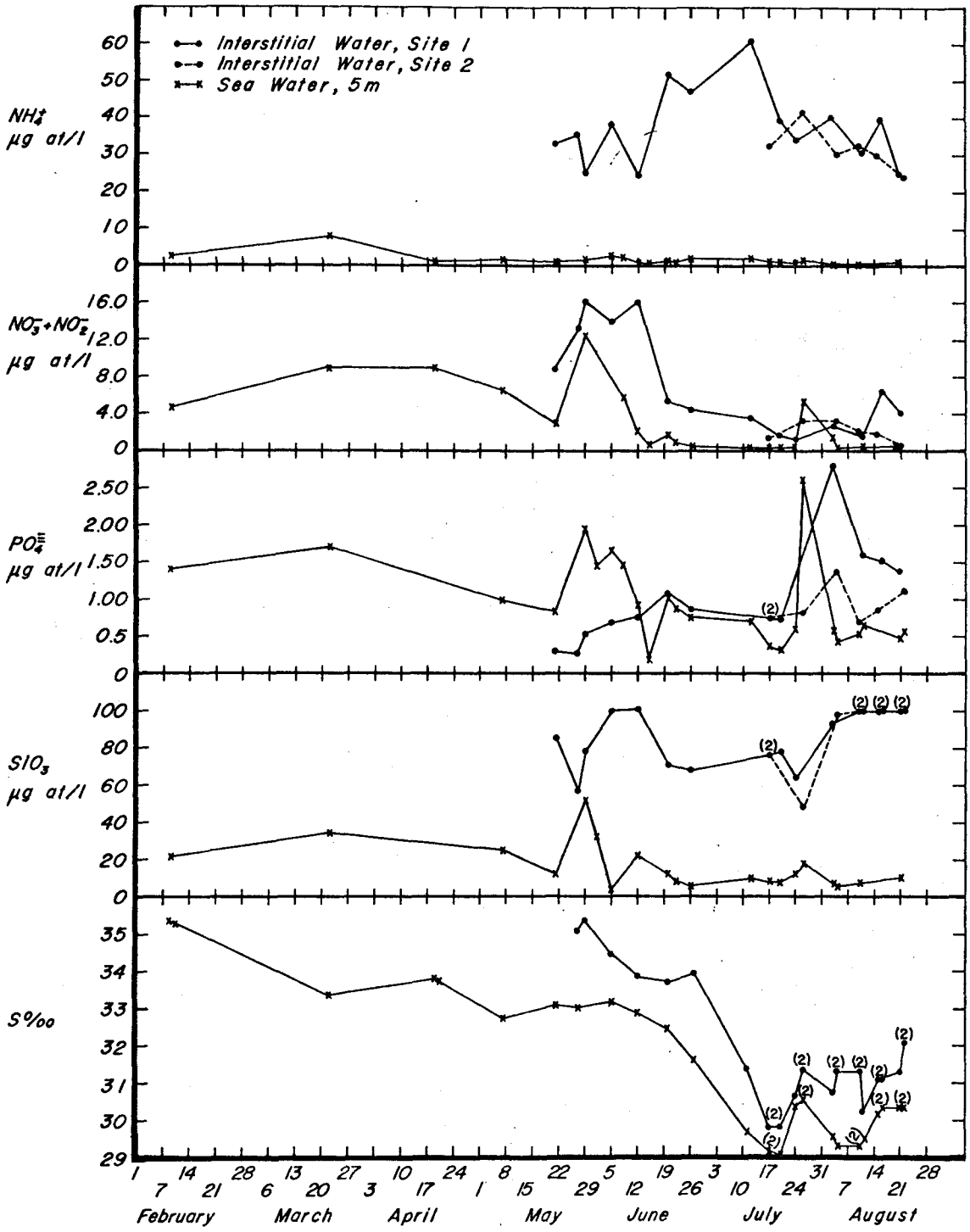

Ice cover
Break up
Surface Intensity
Intensity at sediment-water interface
% of surface intensity
(2)
(2)
(2)
(2)
(2)
100,000
10,000
1000
100
Light Intensity (Lux)
80
70
60
50
40
30
20
10
0
Intensity at Sediment Water Interface as % of Surface Intensity
7
14
21
28
4
11
18
25
2
9
16
23
30
6
13
20
27
May
June
July
August

Figure 16. Salinity and nutrient concentrations of the interstitial water and the water column. (5m depth).


Interstitial Water, Site 1
Interstitial Water, Site 2
Sea Water, 5m
NH4+ µg at/l
NO3+NO2 µg at/l
PO4≡ µg at/l
SiO3 µg at/l
S‰
February
March
April
May
June
July
August

this time was below 1,000 lux and remained below this level until much of the snow cover had melted and melt ponds began to form on the surface of the ice. After the ice had broken up light levels were generally higher although on four occasions light levels after breakup were as low as on the last station taken before breakup. Daily variations in light intensity at the sediment-water interface were probably due to changes in the amount of detritus and plankton in the water. Divers noted that the underwater visibility was greatly affected by the amount of plankton present and that it varied greatly depending upon current conditions.

The salinity of water samples taken at about five meters varied from 35.31 $^{o}/_{oo}$ on 9 February 1972 to 29.15 $^{o}/_{oo}$ on 20 July 1972. This drop in salinity was caused by the addition of low salinity water from the melting ice. The salinity of the interstitial water was always higher than the salinity in the overlying water but it also reflected the decrease in salinity caused by the addition of low salinity meltwater (Fig. 16).

While the concentrations of inorganic nutrients were almost invariably higher in the interstitial water than in the overlying water column, the concentrations of nitrate plus nitrite and phosphate were only slightly greater in the interstitial water (Fig. 16). In contrast, concentrations of ammonia and silicate were both much

higher in the interstitial water than in the water overlying the sediments; ammonia concentrations were over an order of magnitude higher in the interstitial water and silicate concentrations were from two to five times greater. During the months of July and August concentrations of nitrate plus nitrite and ammonia in the water were low (Fig. 16).

DISCUSSION

Bloom development in the benthic biotope appears to be closely linked to melting of shorefast ice and its snow cover which regultes the amount of light energy available at the sediment-water interface. Unfortunately there are no measurements of light intensity at the sediment-water interface prior to May 1972. However, using extinction coefficients reported by Thomas (1963) for snow and shorefast ice near the Naval Arctic Research Laboratory, Barrow, I_z/I_o ratios (intensity at depth z/incident intensity) for snow and ice cover have been calculated (Table 5). During February, when the ice was about 105 cm thick and snow cover was about 5 cm, 3.7% of the surface intensity would penetrate to the ice-water interface assuming the snow was of moderate grain size. However, solar radiation at this time is low (Table 6) and the actual light energy penetrating the ice would be low. Solar radiation increases by two orders of magnitude by early May. However, ice thickness had increased to 170 cm at this time and the calculated attenuation by snow and ice would reduce light intensity at the ice-water interface to about 0.9% of surface intensity. This computed value is in close agreement with the first measurements of light intensity taken at the sampling site on 7 May ($I_{\text{ice-water interface}}$ = 0.8% of I_o). By early June melt ponds began to form. With the growth

Table 5. Light absorption by snow and sea ice

Table 5a. Extinction coefficients (k) and I_z/I_o ratios for snow and sea ice

Medium*	Type*	Density* (g/cm^3)	k* cm^{-1}	Depth cm	$\frac{I_z}{I_o}$
Snow	Fresh	0.087	0.401	5	0.135
				20	<0.001
Snow	Wet	0.348	0.246	5	0.292
				20	0.007
Snow	Moderate grain	0.500	0.196	5	0.375
				20	0.019
Snow	Corn	0.720	0.085	5	0.653
				20	0.182
Ice	Shorefast	0.870	0.0219	105	0.100
				170	0.024

*Thomas (1963)

Table 5b. Measured I_z/I_o at the ice-water interface, spring 1972

	7 May	21 May	27 May	29 May	1 Jun	20 Jun	26 Jun
$\frac{I_z}{I_o}$	0.008	0.005	0.019	0.040	0.085	0.064	0.167

Table 6. Total daily direct solar radiation in gm Cal/cm^2 received on a horizontal surface at 70° North (from Scott, 1964)

4 Feb	21 Mar	6 May	22 Jun	8 Aug	23 Sept	8 Nov	22 Dec
5	205	589	797	583	202	5	0

of the melt ponds and the deterioration of the ice, penetration of light to the ice-water interface increased from 4% on 29 May to 16.7% on 26 June (Table 5b).

An increase in primary productivity (Fig. 9) coincided with the development of melt ponds and the increase in light intensity at the sediment-water interface (Fig. 15). During the same time period chlorophyll *a* values also increased slightly to about 80 mg chl a/m^2 from a baseline level which ranged from 34 to 60 mg chl a/m^2 (Fig. 10) from March until the end of May. Shortly prior to this, on 25 May, divers noticed the presence of small brown patches (9-18 cm^2) on the sediment. These patches increased in area until on 26 June they covered 50-75% of the surface area at site 1. Samples of the brown patches and clear areas were taken. Microscopic examination of samples drawn from the brown patches showed that they contained large numbers of pennate diatoms, including *Pleurosigma stuxbergii*, *Pleurosigma longum*, *Gyrosigma fasciola* and *Gyrosigma spencerii*. Chlorophyll *a* determinations (Table 7) showed that concentrations were significantly higher in the brown patches than in the control areas. Several small patches (3-5 cm^2) of *Amphipleura rutilans* were noticed in the sampling area on 22 June. Sampling was discontinued on 26 June due to the weakness of the ice.

Table 7. Chlorophyll *a* concentrations in brown patches and control areas

	15 June 1972		22 June 1972	
	Chl *a* (mg/m^2)	Phaeopigments (mg/m^2)	Chl *a* (mg/m^2)	Phaeopigments (mg/m^2)
Brown colored cores				
Core 1	73.98	125.93	130.13	220.08
Core 2	77.79	132.78	144.97	195.73
Core 3	79.54	113.89	171.72*	230.15
Core 4	108.67	155.87	———	———
$\bar{X}$	85.00	132.32	148.94	215.32
S^2	254.66	311.72	444.26	313.18
S	15.96	17.66	21.08	17.70
Grey colored cores				
Core 1	30.50	116.18	44.92	139.54
Core 2	28.69	92.75	43.76	125.65
Core 3	25.54	113.91	48.46	124.48
Core 4	27.70	119.09	———	———
$\bar{X}$	28.11	110.48	45.71	129.89
S^2	4.28	144.19	5.99	70.18
S	2.07	12.01	2.45	8.37

*contained small patch of *Amphipleura rutilans*

When sampling was resumed in July, the bottom in the vicinity of site 1 was covered with a mat of *Amphipleura rutilans*. Primary productivity and chlorophyll *a* values increased dramatically (Figs. 9 and 10) probably due to increases in available light during and immediately after the breakup of the shorefast ice. On 8 August a storm with winds of over 30 mph deposited a layer of sediment and detritus about 1 cm thick over the *A. rutilans* mat. This apparently caused a reduction in primary productivity on 10 and 11 August at sites 2 and 1 respectively (Fig. 9). At site 1 a brown layer of motile diatoms was observed on the surface of the newly deposited sediment layer and many of the strands of *A. rutilans* were visible above the sediment. This probably accounts for the smaller reduction in productivity at this station. A peak in chlorophyll *a* was found in the 2nd cm of sediment on 11 August as a result of the *A. rutilans* mat being covered by the layer of sediment.

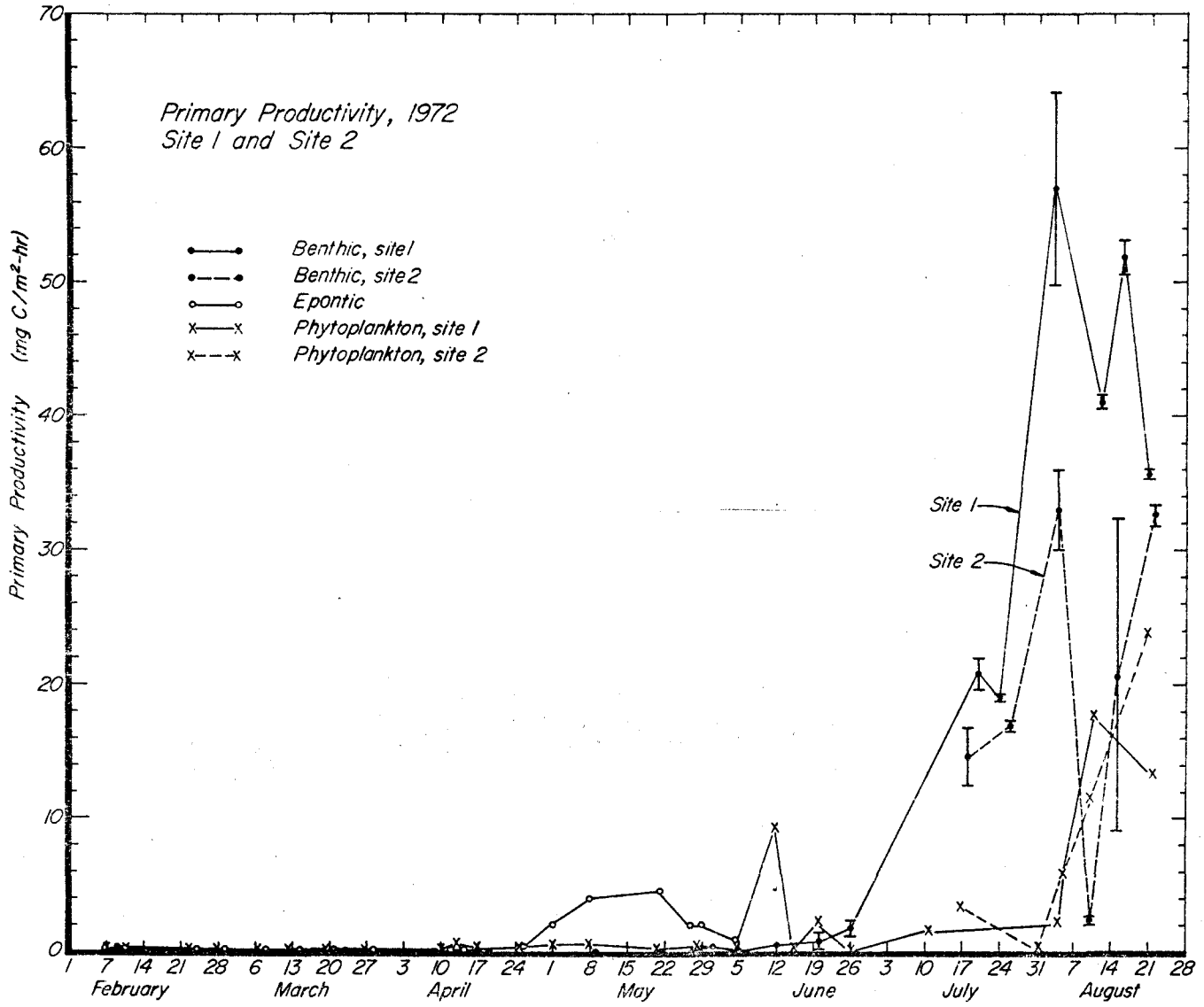
During July and August primary productivity and chlorophyll *a* values were higher at site 1 than at site 2 (Figs. 9 and 10). The reasons for these differences are unclear. The water depth at both stations is the same and there was no significant difference in the sediment composition (Appendix B), salinity (Fig. 16), or light intensity at the sediment-water interface (Fig. 15). The

inorganic phosphate concentrations in the interstitial water were slightly lower at site 2 but they appear to be above what might be expected to be limiting levels.

Figure 17 compares the productivity of the ice algae, the phytoplankton and the benthic microalgae. There was a bloom within the bottom layer of the sea ice during May, and primary productivity reached about 5 mg C/m^2-hr. The productivity of the phytoplankton and the benthic microalgae began to increase following this bloom. This was probably due to increased light levels caused by the disappearance of the brown algal layer in the ice as well as melting of the ice. Benthic microalgae became the most important source of primary productivity in this system after the shorefast ice had broken up. Primary productivity of the benthic microflora reached a peak at site 1 an order of magnitude higher than that of the ice algae and twice the maximum for the phytoplankton.

The absence of data for the period from September to February precludes calculation of an annual mean productivity for the benthic microalgae. However, one would expect productivity to be negligible from the time that the shorefast ice formed in late September until February and the annual average productivity is probably not more than about 5 mg C/m^2-hr. The maximum productivity

Figure 17. Primary productivity of the ice algae, phytoplankton and benthic microalgae. Vertical bars are used to represent the standard deviation.


Primary Productivity, 1972
Site I and Site 2
Benthic, site1
Benthic, site2
Epontic
Phytoplankton, site I
Phytoplankton, site 2
Primary Productivity (mg C/m²-hr)
Site I
Site 2
0
10
20
30
40
50
60
70
1 7 14 21 28 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28
February
March
April
May
June
July
August

is about an order of magnitude less than that reported by Grøntved (1960, 1962) and Gargas (1970) for shallow waters and intertidal areas in Denmark (Table 8). However it is about four times greater than that reported by Bunt, Lee and Lee (1972) for sediments at depths of 10 to 16 m in the Caribbean Sea. Chlorophyll *a* values are about two to three times those reported by Bunt *et al.* (1972) if you correct their chlorophyll *a*-phaeopigment values using their estimate that chlorophyll *a* constituted 45 to 84% of the chlorophyll-phaeopigment total (Table 9). The chlorophyll *a* data for Barrow in µg Chl *a*/g sediment (4-38 µg/g) is similar to that found by Leach (1970) in an intertidal mudflat and by Steele and Baird (1968) for a sandy beach (Table 9).

The existence of small scale patchiness is suggested by the large standard deviations of replicate cores for primary productivity and chlorophyll *a* (Figs. 9 and 10, Appendix C) determinations which were taken within about 5 cm of each other (Fig. 3). The presence of brown patches of epipelic algae during the month of June corroborates this evidence. Several other investigators (Fenchel and Straarup 1971; Grøntved 1960, 1962) have reported the presence of small scale patchiness in the distribution of benthic microalgae. Bunt *et al.* (1972) found that the "within-site pigment concentrations were highly variable ... in an apparently homogeneous area of intertidal

Table 8. Primary Productivity of various

Primary Productivity	Habitat or Association	Water Depth
8.1 mg C/m^2-hr mean	calcareous sediment	10-16 m
125 mg C/m^2-hr annual mean	epipsammic algae	0.5 cm
31 mgC/m^2-hr annual mean	epipelic algae	0.5-2 cm
305 mgC/m^2-hr maximum	epipsammic algae	0-1 cm
71 mgC/m^2-hr annual mean	sand bottom	0.85 m
68 mgC/m^2-hr annual mean	sand-mud-clay	1.11 m
ca. 340 mgC/m^2-hr maximum	-	0.7 m
256 mgC/m^2-hr annual mean	sand, epipsammic algae	intertidal
53.3 mgC/m^2-hr annual mean	sand-mud-silt epipelic algae	intertidal
550 mgC/m^2-hr maximum	sand-mud-silt	intertidal

benthic habitats

Location	Reference
Caribbean Sea	Bunt, Lee and Lee (1972)
Niva Bay, Denmark	Gargas (1970)
Niva Bay, Denmark	Gargas (1970)
Niva Bay, Denmark	Gargas (1970)
Danish fjords	Grøntved (1960)
Danish fjords	Grøntved (1960)
Danish fjords	Grøntved (1960)
Danish Wadden Sea	Grøntved (1962)
Danish Wadden Sea	Grøntved (1962)
Danish Wadden Sea	Grøntved (1962)

Table 8. (continued)

Primary Productivity	Habitat or Association	Water Depth	Location	Reference
48.7 mgC/m^2-hr annual mean	epipsammic algae	-	Shear Water, England	Hickman and Round (1970)
1.72 mgC/m^2-hr annual mean	epipelic algae	-	Shear Water, England	Hickman and Round (1970)
9.8 mgC/m^2-hr annual mean	mud, epipelic algae	intertidal	Intertidal mudflat, England	Leach (1970)
ca. 24 mgC/m^2-hr maximum	mud, epipelic algae	intertidal	Intertidal mudflat, England	Leach (1970)
ca. 68.8 mgC/m^2-hr annual mean	mud, epipelic algae	intertidal	Salt marsh, Georgia	Pomeroy (1959)
ca. 195 mgC/m^2-hr maximum	mud, epipelic algae	intertidal	Salt marsh, Georgia	Pomeroy (1959)
1.2-2.7 mgC/m^2-hr* annual mean	sand	0-13 m	Loch Ewe, Scotland	Steele and Baird (1968)
61 mgC/m^2-hr annual mean	mud-sand-pebbles	0-1 m	Borax Lake, California	Wetzel (1964)
ca. 390 mgC/m^2-hr maximum	mud-sand-pebbles	0-1 m	Borax Lake, California	Wetzel (1964)

*quoted from Bunt, Lee and Lee (1972)

Table 9. Chlorophyll *a* concentrations of

Chlorophyll *a*	Habitat or Association	Water Depth
17-219 mg/m^2 (chlorophyll & phaeopigment)	calcareous sediment	10-16 m
1.5-3.9 mg/m^2	epipsammic algae	50 cm
10.2-19.9 mg/m^2	epipsammic algae	shoreline
66.0-76.5 mg/m^2	epipsammic algae	5-20 cm
0-200 mg/m^2	epipsammic algae	-
2-14 mg/m^2	epipelic algae	-
23-35 µg/g	epipelic algae	intertidal
380-750 mg/m^2	blue-green algal mat	10 cm
3-20 µg/g	epipsammic algae	0-13 m
200-400 mg/m^2	mud-sand-pebbles	0-1 m

various benthic habitats

Location	Reference
Caribbean Sea	Bunt, Lee and Lee (1972)
Helsingør Beach, Denmark	Fenchel and Straarup (1971)
Helsingør Beach, Denmark	Fenchel and Straarup (1971)
Niva Bay, Denmark	Fenchel and Straarup (1971)
Shear Water, England	Hickman and Round (1970)
Shear Water, England	Hickman and Round (1970)
Ythan Estuary, Scotland	Leach (1970)
Salt Pond, Texas, USA	Odum, McConnell and Abbott (1958)
Loch Ewe, Scotland	Steele and Baird (1968)
Borax Lake, California, USA	Wetzel (1964)

sediment." Grøntved (1961) suggested that patchiness was related to the mud content of the sediment. Divers noticed that the brown patches of epipelic algae, when first observed at Barrow, were usually found in troughs or depressions where the mud content would be expected to be highest. However, in a series of five linear regression analyses (Appendix B) of the % silt-clay (mud) and the chlorophyll *a* content of cores, only one set of samples showed a significant correlation between these parameters ($p<0.05$). More study is needed in order to understand the causes of this small scale patchiness. The use of a technique similar to that developed by Brock and Brock (1967) which would allow the use of one core to measure several different parameters might provide some clues to the cause of this variability.

Chlorophyll *a* concentrations were surprisingly high during the winter months when the benthic microalgae were subjected to a long period of darkness and primary productivity was negligible. In addition, chlorophyll *a* levels remained more or less constant in the 2nd, 3rd and 4th cms of sediment throughout the sampling period. Microscopic examination of samples taken from the lower levels of sediment showed that many of the cells were healthy and often contained oil storage products. These observations were also true of the upper centimeter of sediment during February and March. Thus, a

substantial number of algae appear to spend much of their time out of the photic zone. Previous investigations of the benthic microalgae have shown the presence of pigmented cells well below the photic zone (Fenchel and Straarup 1971; Grøntved 1962; Steele and Baird 1968; Meadows and Anderson 1968). Horner and Alexander (1972) and Rodhe (1955) reported the presence of viable cells in the darkness in ice covered ecosystems. Heterotrophic uptake of dissolved organic substrates has been suggested as an energy source for photosynthetic organisms in environments where long periods of darkness occur (Wilce 1967; Wood 1956). As a result of investigations in Loch Ewe, Scotland, by Steele and Baird (1968), Munro and Brock (1968) investigated the heterotrophic potential of the sand community there. They found that bacteria alone were responsible for heterotrophic uptake and that algal heterotrophy was negligible in this system. These observations agree with the findings of Horner and Alexander (1972) for the epontic community at Barrow. Several investigators (Antia and Cheng 1970; Curl and McLeod 1961) have offered another solution to this problem by demonstrating that axenic cultures of diatoms are capable of surviving in the darkness for periods of up to two months. Additional study is required to determine how the benthic microalgae at Barrow are able to survive long periods of darkness. This should include an investigation of

heterotrophic uptake by this community as well as attempts to maintain axenic cultures of the major species in the dark for extended periods of time.

It is difficult to evaluate whether cells from the epontic community make a significant contribution to the benthic microalgae after they have disappeared from the ice. Chlorophyll *a* and primary productivity values do show a slight increase following the bloom in the ice (Figs. 10 and 17) but this is probably a response to increased light levels rather than the addition of cells from the ice community. There are, however, some similarities between the species assemblages in these two communities. Meguro, Ito and Fukushima (1966, 1967) listed 24 species of pennate diatoms in 7 genera present in the sea ice at Barrow but gave no indication of their relative abundance. Of these 24 species, 5 are also found in the sediment. Horner and Alexander (1972) found that *Nitzschia frigida* Grunow was the most common species present in the sea ice. *Amphiprora hyperborea*, *Fragilariopsis oceanica* (Cl.) Hasle (=*Nitzschia grunowii* Hasle) and *Nitzschia closterium* were reported to be abundant. *Pleurosigma stuxbergii*, *Gomphonema exiguum*, v. *arctica*, other species of *Nitzschia* and several species of *Navicula* were listed as present. Two of the species listed as common, *Amphiprora hyperborea* and *Fragilariopsis oceanica* were also found in the sediment during this study (Table 4)

and one of the species listed as present, *Pleurosigma stuxbergii*, was dominant in the sediment until the *Amphipleura rutilans* bloom began. *Gyrosigma fasciola* which was common in the sediment was present in samples of the ice algae examined by the author. Several of the unidentified species of *Navicula* found in the ice are also found in the benthic biotope. A more detailed taxonomic study is needed to determine any further similarities that may exist between these two communities.

Because no data are available on the utilization of the benthic microflora at Barrow one can only speculate on the significance of these organisms to higher trophic levels. MacGinitie (1955) made extensive collections of benthic invertebrates near the Naval Arctic Research Laboratory from 1948 to 1950. This study was essentially descriptive in nature and the data do not allow comparison of biomass with other areas. However, Ellis (1960) found that the biomass of the infauna in the neritic zone of the Canadian Arctic and western Greenland was from 2 to 44 gm/m^2 (dry weight). MacGinitie (1955) collected 20 species in 18 genera of benthic invertebrates (Table 10). in samples taken from a shallow near-shore area ($\leq$ 10 m depth) including the sampling sites utilized during this investigation. During the present study, divers observed the presence of polychaetes echiuroids, sipunculids, the hermit crab, *Pagurus* sp., and the clam,

Table 10. Benthic invertebrates reported by MacGinitie (1955) in shallow areas (< 30 m) of the Chukchi Sea near Barrow

Hydroids

Corymorpha sp.
Obelia sp.

Nemerteans

Amphiporeas lactifloreus
A. pacificus
A. macracanthus
Lineus ruber
Micrura alaskanus
Tubulanus capistratus

Bryozoans

Alcyonidium disciforme

Echiuroids

Echiurus echiurus alaskanus

Polychaetes

Phylodoce groenlandica
Pectinaria granulata

Holothurians

Myriotrochus rinki
Psolus fabricii

Tunicates

Rhizomolgula globularis

Amphipods

Atylus carinatus
Weyprechtia heuglini
Acanthostepheia beringiensis

Isopods

Idotaega entomon

Mya truncata which were not found by MacGinitie (1955). Seven of the 20 species observed by MacGinitie (1955) are primarily deposit feeders and among the additional forms observed by divers some of the polychaetes and the sipunculids are probably deposit feeders. In addition to the deposit feeders, suspension feeders in the benthic community may rely on the sediment for a substantial portion of their food (Marshall 1970). As a result of stomach analyses, Sanders *et al.* (1962) found that several invertebrates classified as carnivores or scavengers also feed on benthic algae and detritus. In particular, nemerteans, an amphipod (*Carinogammarus macrunotus*), an isopod (*Edotea montosa*) and the hermit crab, *Eupagurus longicarpus* were found to have ingested benthic diatoms and filamentous algae as well as other food materials. MacGinitie (1955) felt that tundra plants originating from eroding shorelines and riverbanks was the primary source of food material for the benthic fauna near Barrow and throughout much of the neritic zone of the Arctic Ocean. If the productivity of the benthic microflora in the areas studied during this investigation is not a local phenomenon, these plants represent another potential food source for the benthic fauna in nearshore areas.

This study has raised many questions about the ecology of the benthic microflora and it has opened new avenues of inquiry. In

addition to the research suggested above further study is required to determine the extent of the microflora community near Barrow and to determine if similar communities exist in other nearshore environments in the Arctic Ocean. The algal mat of *A. rutilans* which was the source of high levels of primary productivity and biomass during July and August 1972 was not observed by divers during the preliminary investigation made during July and August 1971. However, a mat of filamentous algae was observed by Mr. Stuart Grant who was diving in the same area during the summer of 1971 (R. A. Horner, pers. comm.). This suggests that the development of the algal mat of *A. rutilans* may not be an annual occurrence. Its development may be controlled by some environmental parameter which changes from year to year. Certain physical properties, especially light transmission and currents, exert an obvious influence on the benthic microalgae and greater efforts should be employed to obtain more sophisticated measurements of these properties. Finally, in order to obtain an even rudimentary understanding of the nearshore benthic ecosystem studies on the benthic macrofauna and meiofauna should be undertaken.

SUMMARY

1. The primary productivity of the benthic microalgae appears to be light limited and it remains at low levels until the shorefast ice has broken up and light intensity at the sediment surface increases. Primary productivity reached a maximum of 56.99 and 33.04 mg C/m^2-hr at site 1 and site 2, respectively. Primary productivity values were lower than those found in many intertidal or shoal areas but were four times greater than those reported for tropical sediments at depths of 10-16 m (Table 8).
2. Chlorophyll *a* and primary productivity data indicate the presence of small scale patchiness which can not be explained from the data available.
3. The existence of healthy cells in an environment where they are exposed to prolonged periods of darkness raises the question of how these photosynthetic organisms are able to survive long periods of darkness. Although heterotrophic growth cannot be ruled out, maintenance of a low catabolic rate is suggested as a possible method of surviving long periods of darkness.
4. Some similarities between the ice algae and the benthic microflora have been noted but there is little evidence that

the epontic algae make a substantial contribution to the benthic biotope after they have disappeared from the ice.

5. The benthic microflora may be a significant source of energy for the benthic fauna in the nearshore area near Barrow and in other similar ecosystems in the Arctic Ocean.

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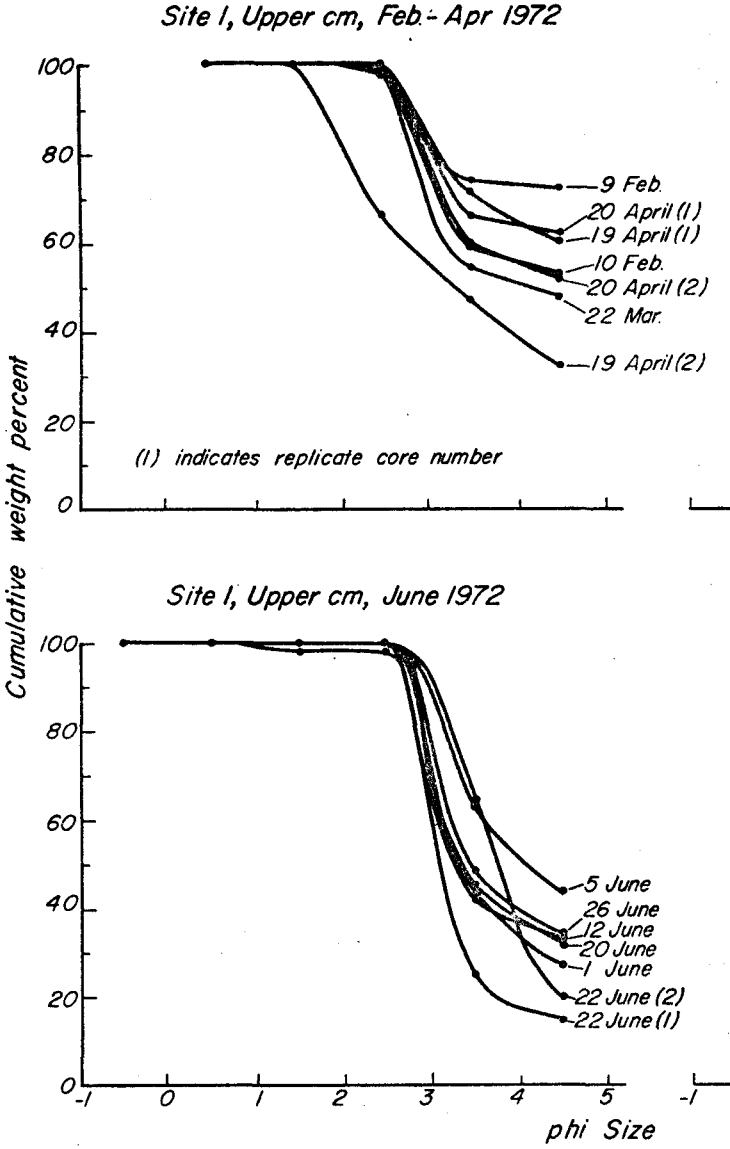
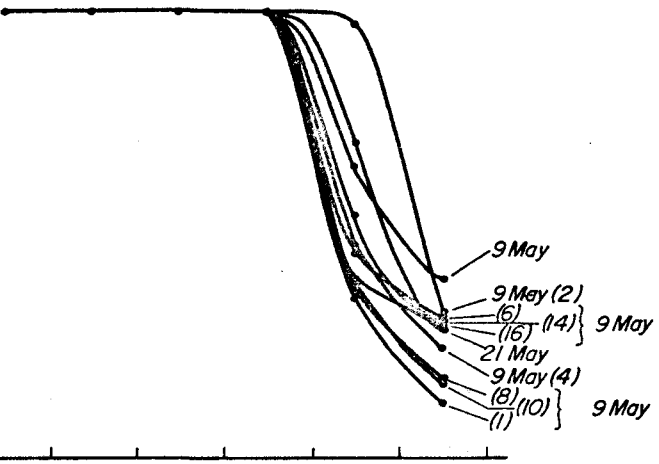
APPENDICES

APPENDIX A

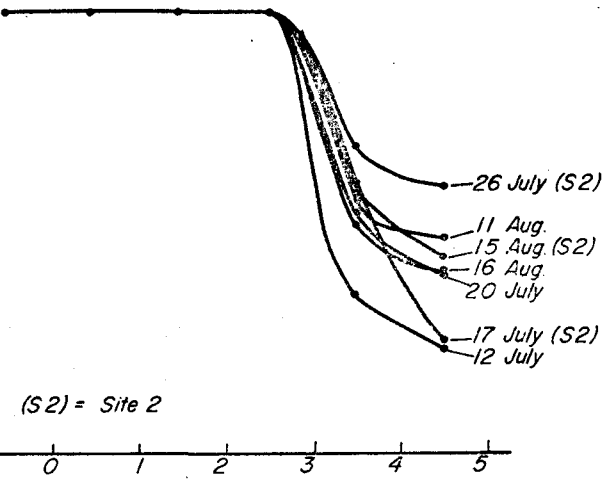
Cumulative frequency distribution of the sediment

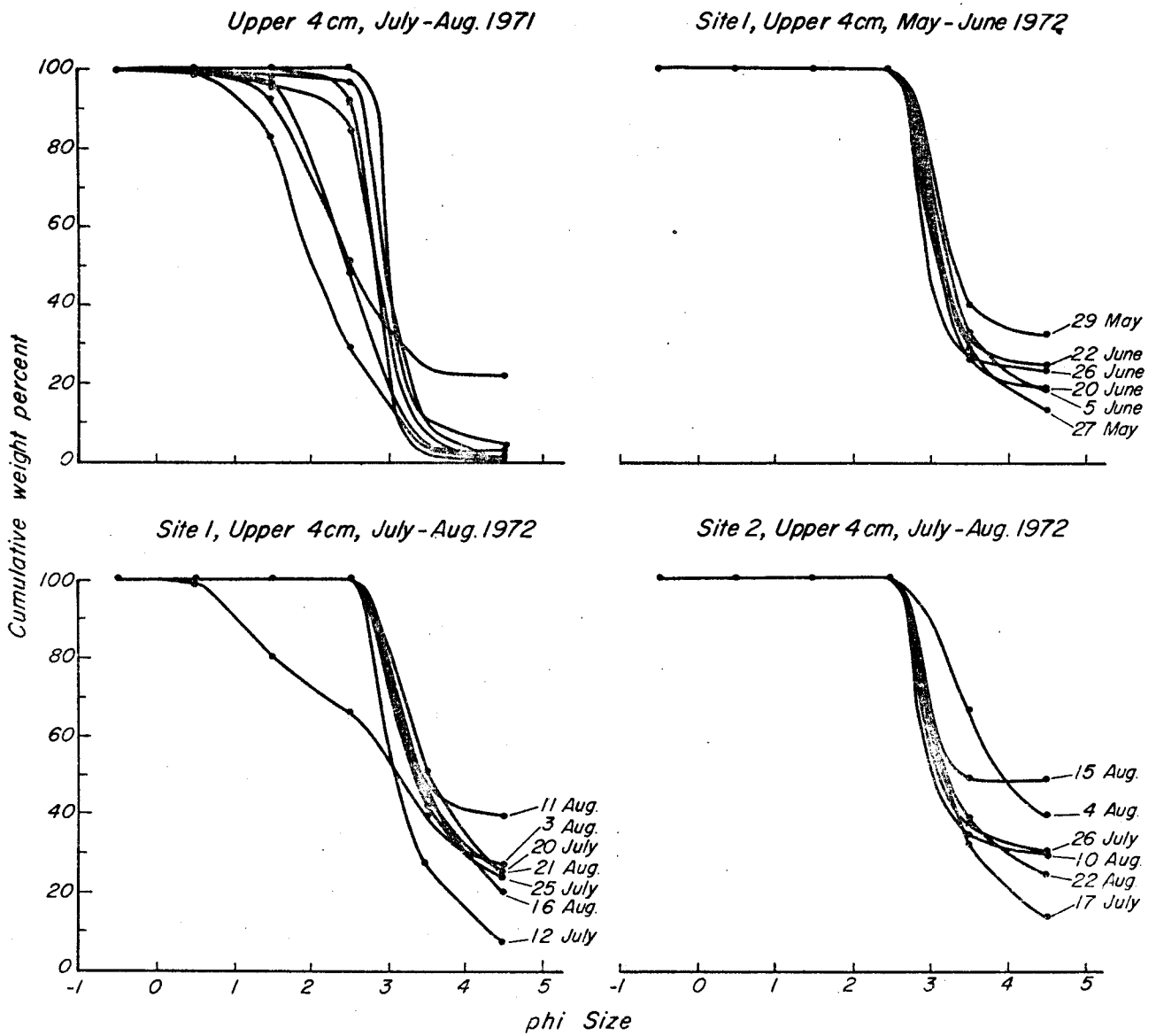

Site I, Upper cm, Feb.- Apr 1972
100
80
60
40
20
0
9 Feb.
20 April (1)
19 April (1)
10 Feb.
20 April (2)
22 Mar.
19 April (2)
(1) indicates replicate core number
Site I, Upper cm, June 1972
Cumulative weight percent
100
80
60
40
20
0
5 June
26 June
12 June
20 June
1 June
22 June (2)
22 June (1)
-1
0
1
2
3
4
5
-1
phi Size

Site 1, Upper cm, May 1972



Site 1 and 2, Upper cm, July-Aug. 1972




Upper 4 cm, July-Aug. 1971
Site I, Upper 4cm, May-June 1972
Site I, Upper 4cm, July-Aug. 1972
Site 2, Upper 4 cm, July-Aug. 1972
Cumulative weight percent
100
80
60
40
20
0
-1
0
1
2
3
4
5
phi Size
29 May
22 June
26 June
20 June
5 June
27 May
11 Aug.
3 Aug.
20 July
21 Aug.
25 July
16 Aug.
12 July
15 Aug.
4 Aug.
26 July
10 Aug.
22 Aug.
17 July

APPENDIX B

Statistical analysis of the results

A. Sediment Analyses

1. Analysis of Variance. Comparison of median phi size in the upper 1 cm from February through April 1972 to that from May through August 1972.

Sources of Variance	Sums of Squares	d.f.	M.S.	F calc.	F(P=0.05)
Season	0.7580	1	0.7580	4.19	4.09
Samples in season	6.8672	38	0.1807		
TOTAL	7.6252	39			

2. Analysis of Variance. Comparison of median phi size in the upper 4 cm at site 1 from July through August 1972 to that at site 2 during the same period.

Sources of Variance	Sums of Squares	d.f.	M.S.	F calc.	F(P=0.05)
Site	0.0092	1	0.0092	0.12	5.12
Samples in site	0.6692	9	0.0737		
TOTAL	0.6721	10			

3. Analysis of Variance. Comparison of median phi size, upper 1 cm, at site 1 from July through August 1972 to that at site 2 during the same period.

Sources of Variance	Sums of Squares	d.f.	M.S.	F calc.	F(P=0.05)
Site	0.0050	1	0.0050	0.04	6.61
Samples in site	0.5835	5	0.1167		
TOTAL	0.5885	6			

B. Linear regression analyses. Chlorophyll *a* concentrations plotted against % silt-clay in the upper 1 cm of a core.

Date (sample)	N	b	a	r calc.	Sy,x	r(P=0.05)
Feb May 72	30	0.12	31.17	0.13	17.64	0.35
9 May 72 (14 cores)	14	0.13	19.29	0.34	7.36	0.53
22 June 72 (6 cores)	6	0.14	18.09	0.82	5.56	0.81
June 72	11	0.19	20.78	0.53	13.00	0.60
July-Aug 72	12	0.03	35.54	0.26	13.55	0.57

where Y = a + bx

N = number of samples

r calc = calculated zero order correlation coefficient

Sy,x = standard error (biased)

r(P=0.05) = correlation coefficient at the 5% significance level

C. Chlorophyll *a* Analysis. (All data reported for the analyses of variance of chlorophyll data are log transformations of the chlorophyll *a* data.)

1. Analysis of variance. Comparison of chlorophyll *a* concentrations for replicate cores taken at a station with all cores taken throughout the period February through August 1972.

a. Upper 1 cm

Sources of Variance	Sums of Squares	d.f.	Mean Square	F calc.	F(P=0.05)
All Cores	4.6969	21	0.2237	16.04	2.07
Replicate Cores	0.3486	25	0.0139		
TOTAL	5.0455	46			

b. 2nd cm

All Cores	0.6168	22	0.0280	2.60	2.88
Replicate Cores	0.2264	21	0.0108		
TOTAL	0.8432	43			

c. 3rd cm

All Cores	2.2610	23	0.0983	1.84	2.83
Replicate Cores	1.1749	22	0.0534		
TOTAL	3.4358	45			

Sources of Variance	Sums of Squares	d.f.	Mean Square	F calc.	F(P=0.05)
d. 4th cm					
All cores	4.5524	23	0.1979	1.83	2.83
Replicate Cores	2.3762	22	0.1080		
TOTAL	6.9286	45			

2. Analysis of Variance. Comparison of chlorophyll *a* concentrations of two subsamples taken per core with subsamples of all cores taken from February through August 1972.

Sources of Variance	Sums of Squares	d.f.	Mean Square	F calc.	F(P=0.05)
All subsamples	91.7839	152	0.6038	28.70	1.34
Subsamples in Cores	3.2188	153	0.0210		
TOTAL	95.0026	305			

3. Nested Analysis of Variance. Comparison of chlorophyll *a* concentrations of subsamples for differences between cores, depths in cores and the error associated with subsamples.

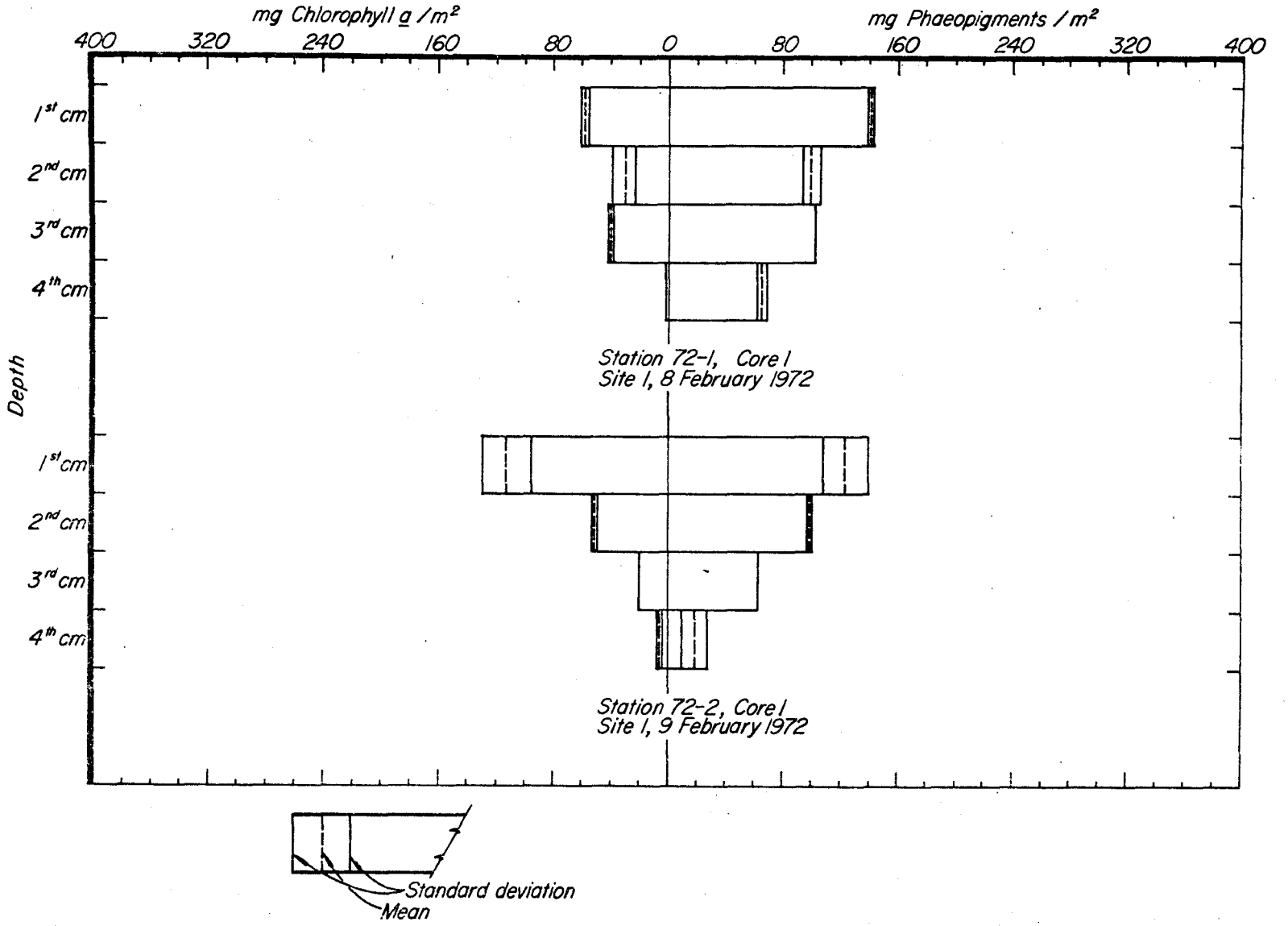
Sources of Variance	Sums of Squares	d.f.	Mean Square	F calc.	F(P=0.05)
Between Cores	13.1519	45	0.2923	0.6596	1.54
Depths in Cores	40.7798	92	0.4432	20.7103	1.39
Error	2.9529	138	0.0214		
TOTAL	56.8846	275			

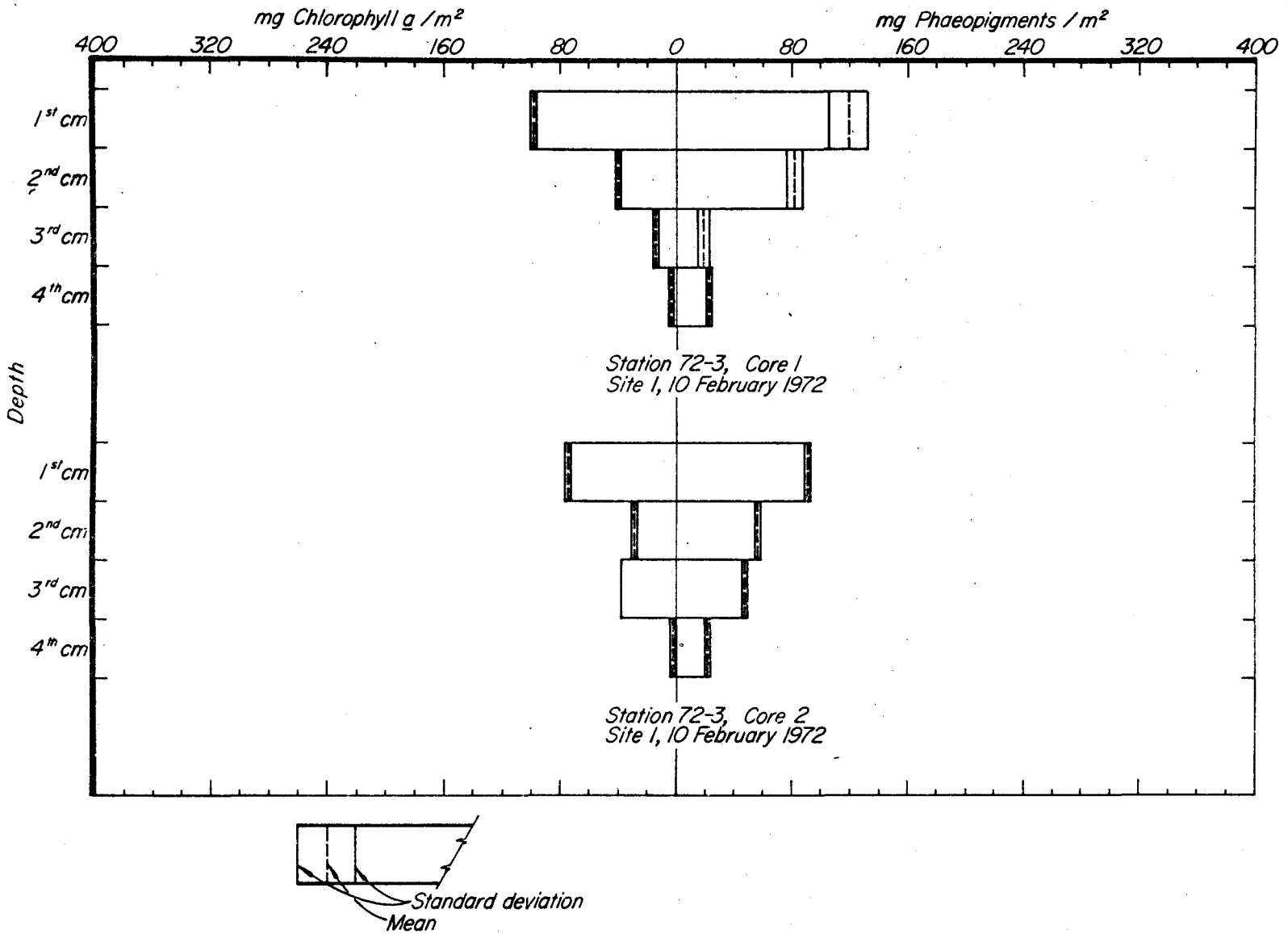
4. Linear Regression Analyses. Chlorophyll *a* concentrations plotted against phaeopigment concentrations in each core for each of 5 of the upper 4 cms.

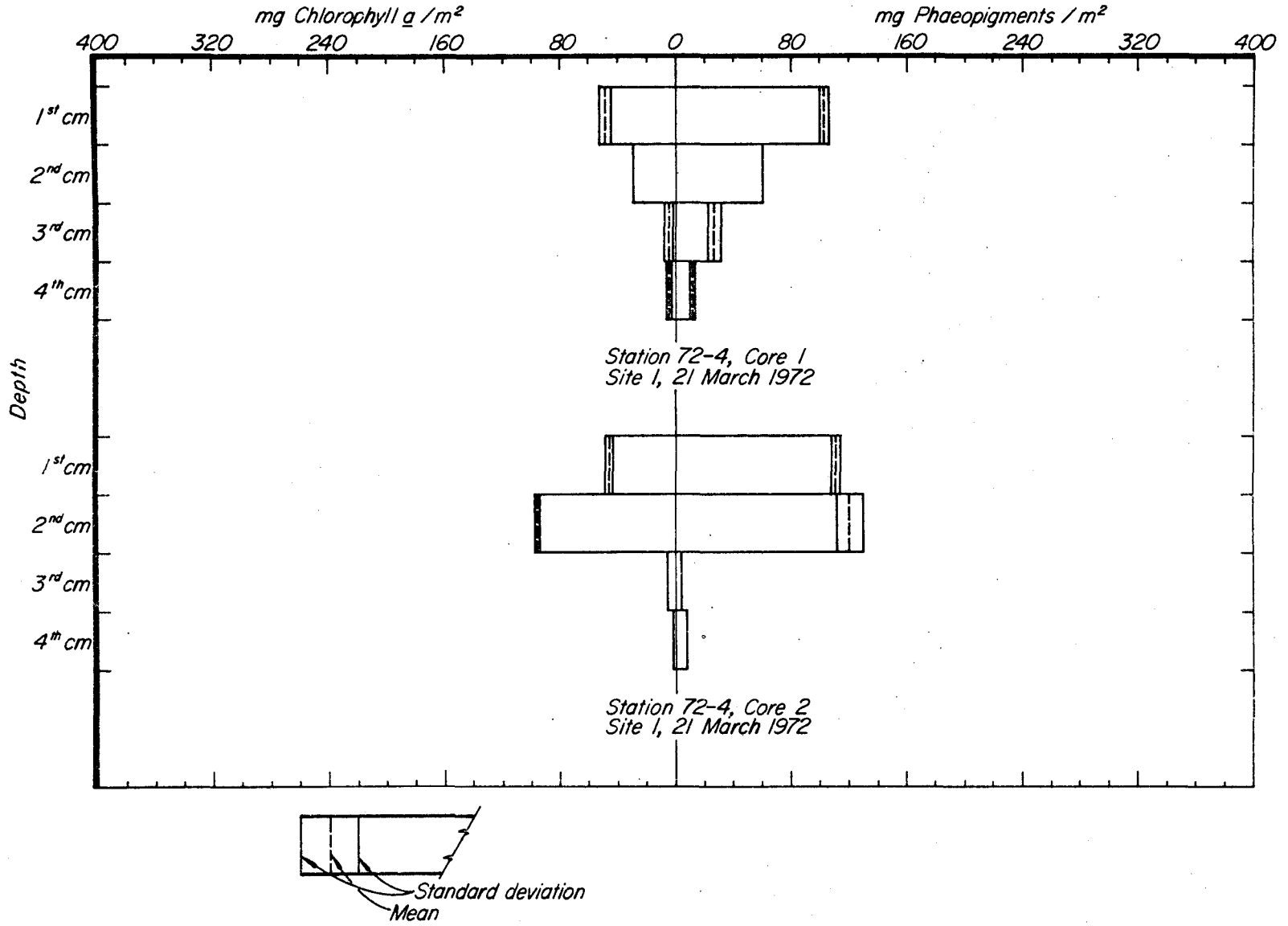
Samples	N	b	a	r	Sy,x	r(P=0.05)
a) 1st cm						
Feb-Aug 72	45	0.71	86.67	0.20	42.45	0.30
Feb-June 72	32	1.34	34.14	0.80	27.50	0.35
July-Aug 72	13	0.49	180.48	0.47	95.56	0.53
b) 2nd cm						
Feb-Aug 72	45	0.70	86.58	0.22	42.41	0.30
Feb-June 72	32	0.95	62.90	0.59	18.02	0.35
July-Aug 72	13	-1.95	240.05	0.41	50.06	0.53
c) 3rd cm						
Feb-Aug 72	46	1.64	41.17	0.50	36.94	0.29
Feb-June 72	32	1.59	29.95	0.65	22.26	0.35
July-Aug 72	14	1.11	82.42	0.31	46.09	0.53
d) 4th cm						
Feb-Aug 72	46	2.54	19.63	0.52	27.73	0.29
Feb-June 72	32	1.76	18.27	0.57	16.99	0.35
July-Aug 72	14	3.61	25.44	0.53	37.17	0.53

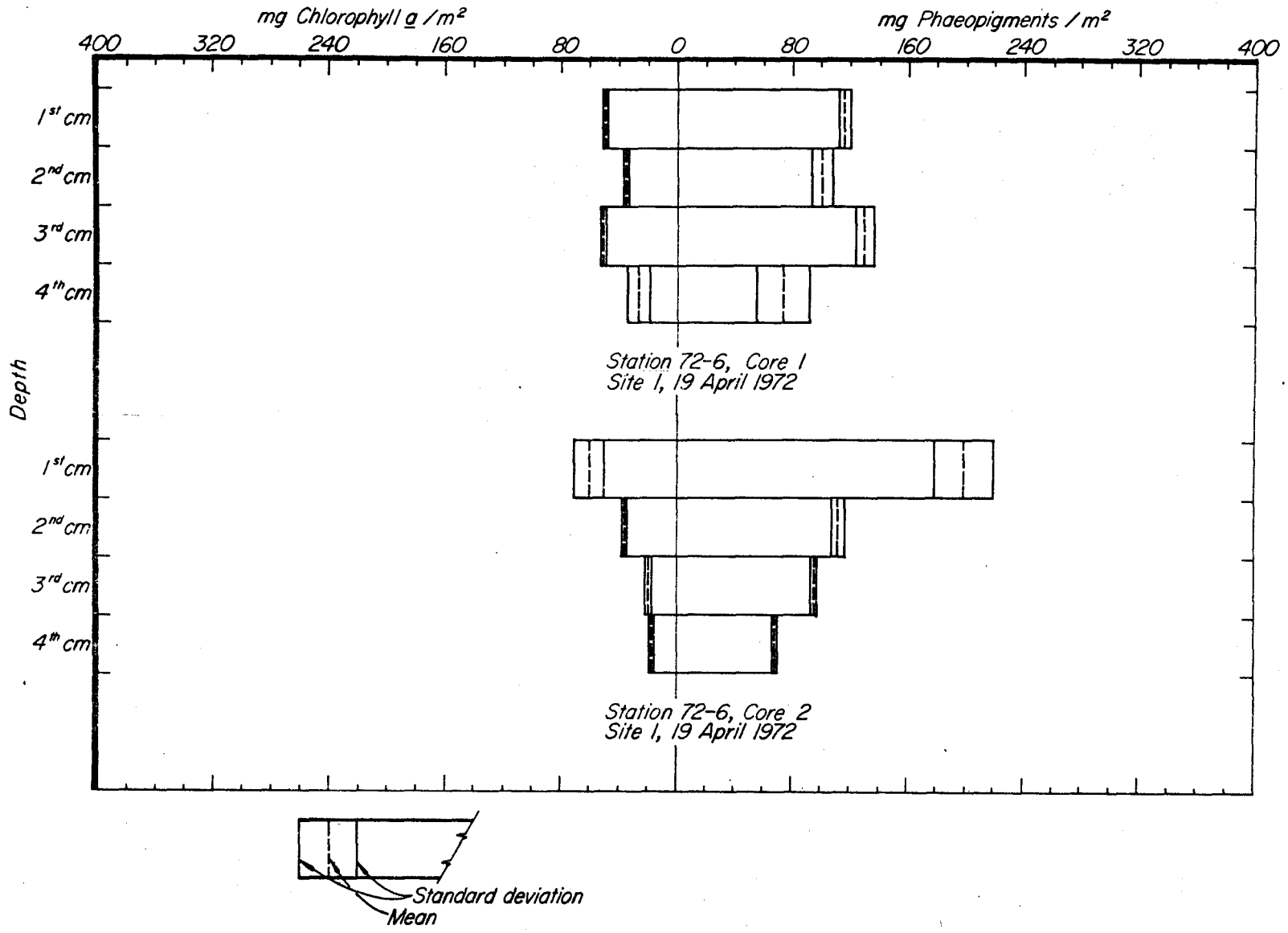
APPENDIX C

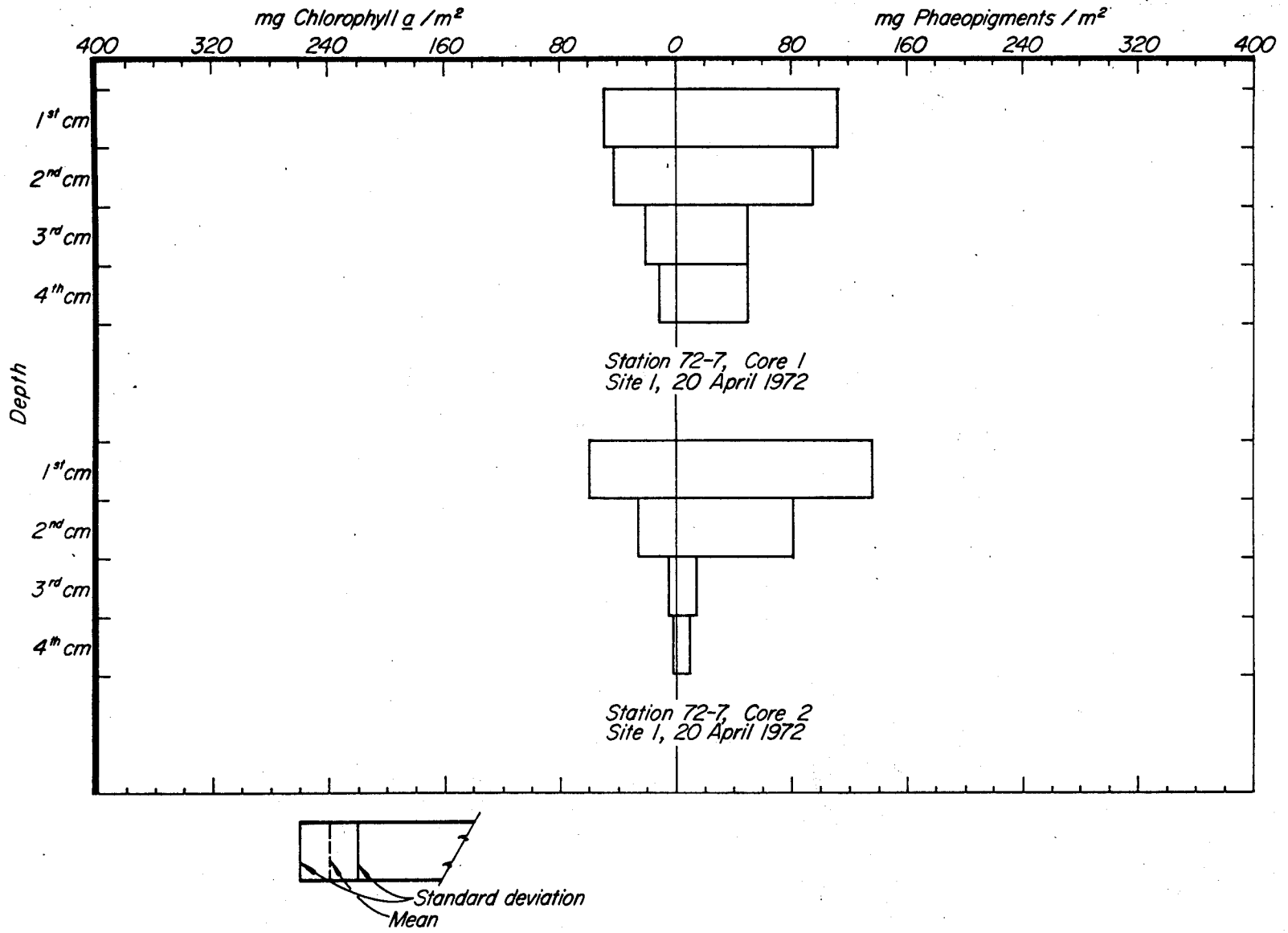
Histograms of chlorophyll *a* and phaeopigment concentrations in the upper 4 cm of sediment

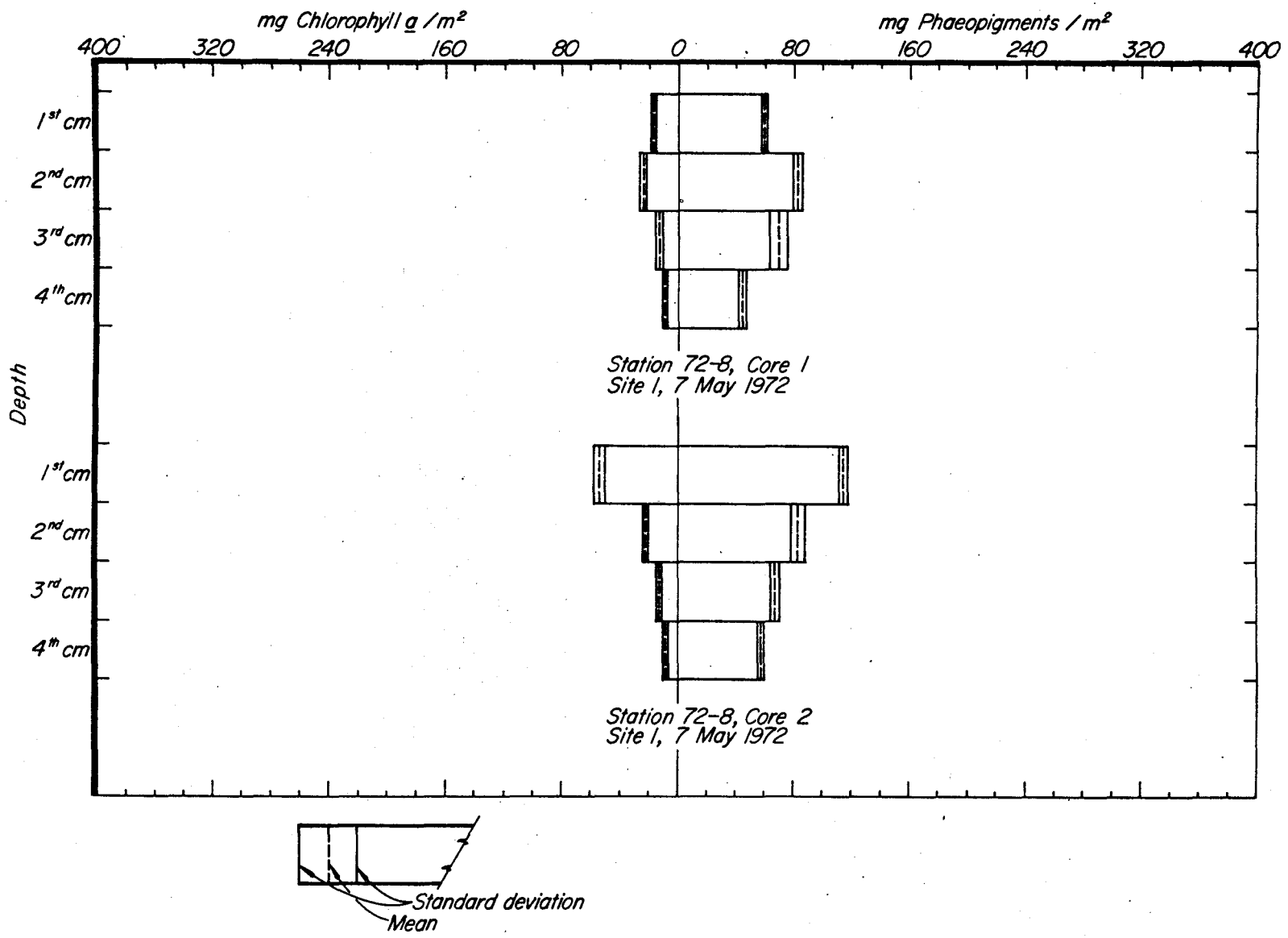

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-1, Core I
Site I, 8 February 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-2, Core I
Site I, 9 February 1972
Standard deviation
Mean

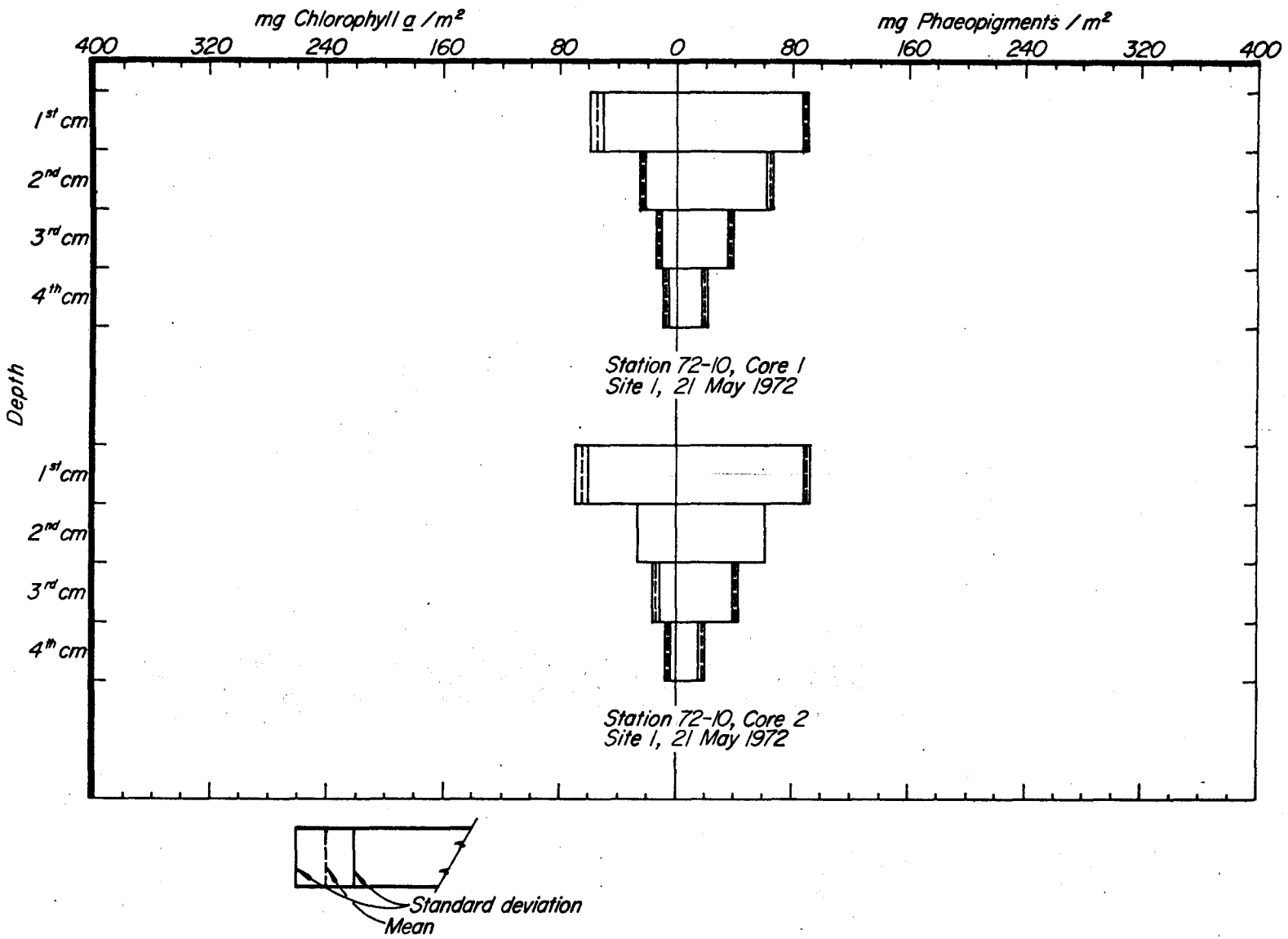

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-3, Core 1
Site 1, 10 February 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-3, Core 2
Site 1, 10 February 1972
Standard deviation
Mean

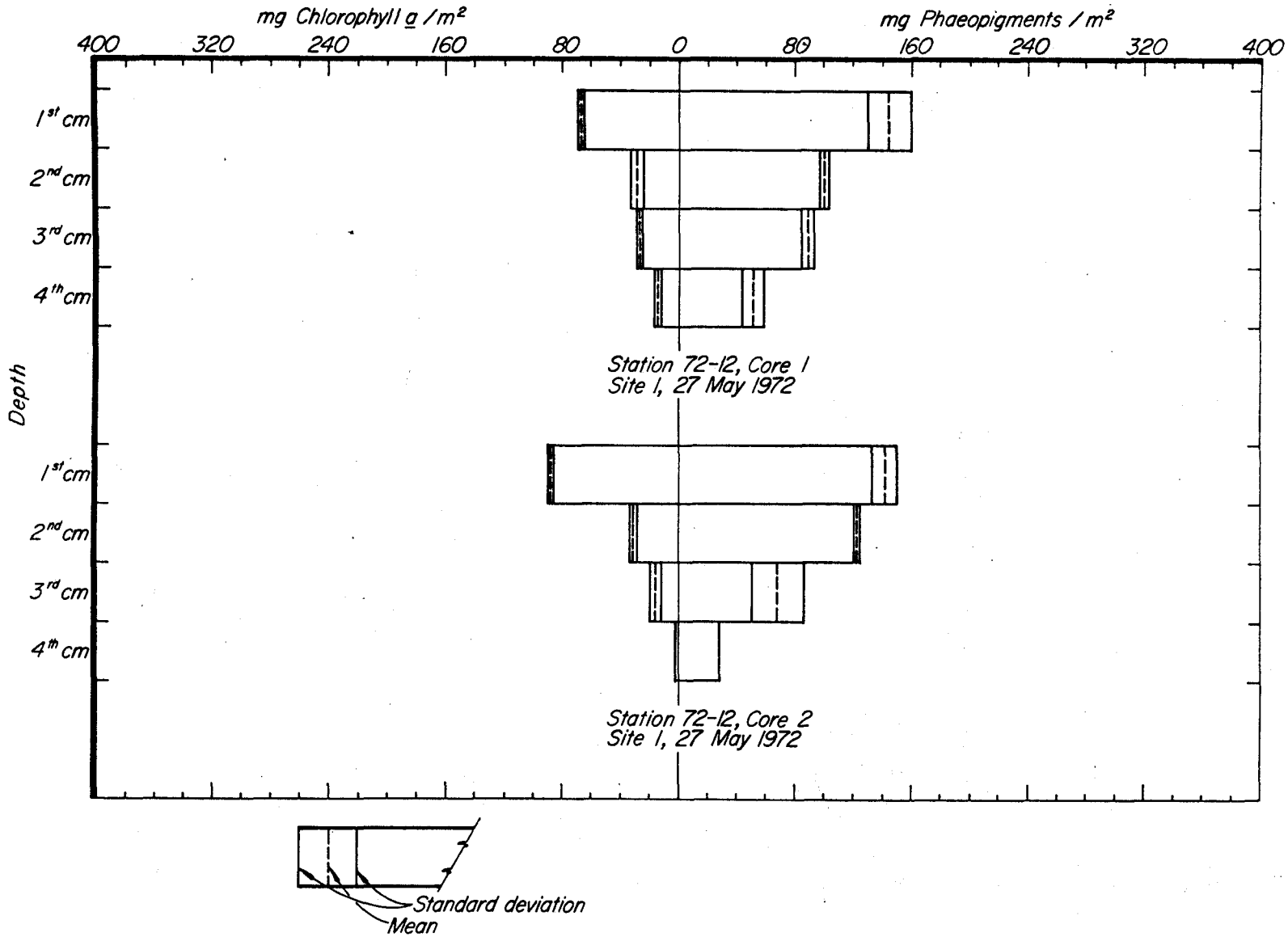

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-4, Core 1
Site 1, 21 March 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-4, Core 2
Site 1, 21 March 1972
Standard deviation
Mean

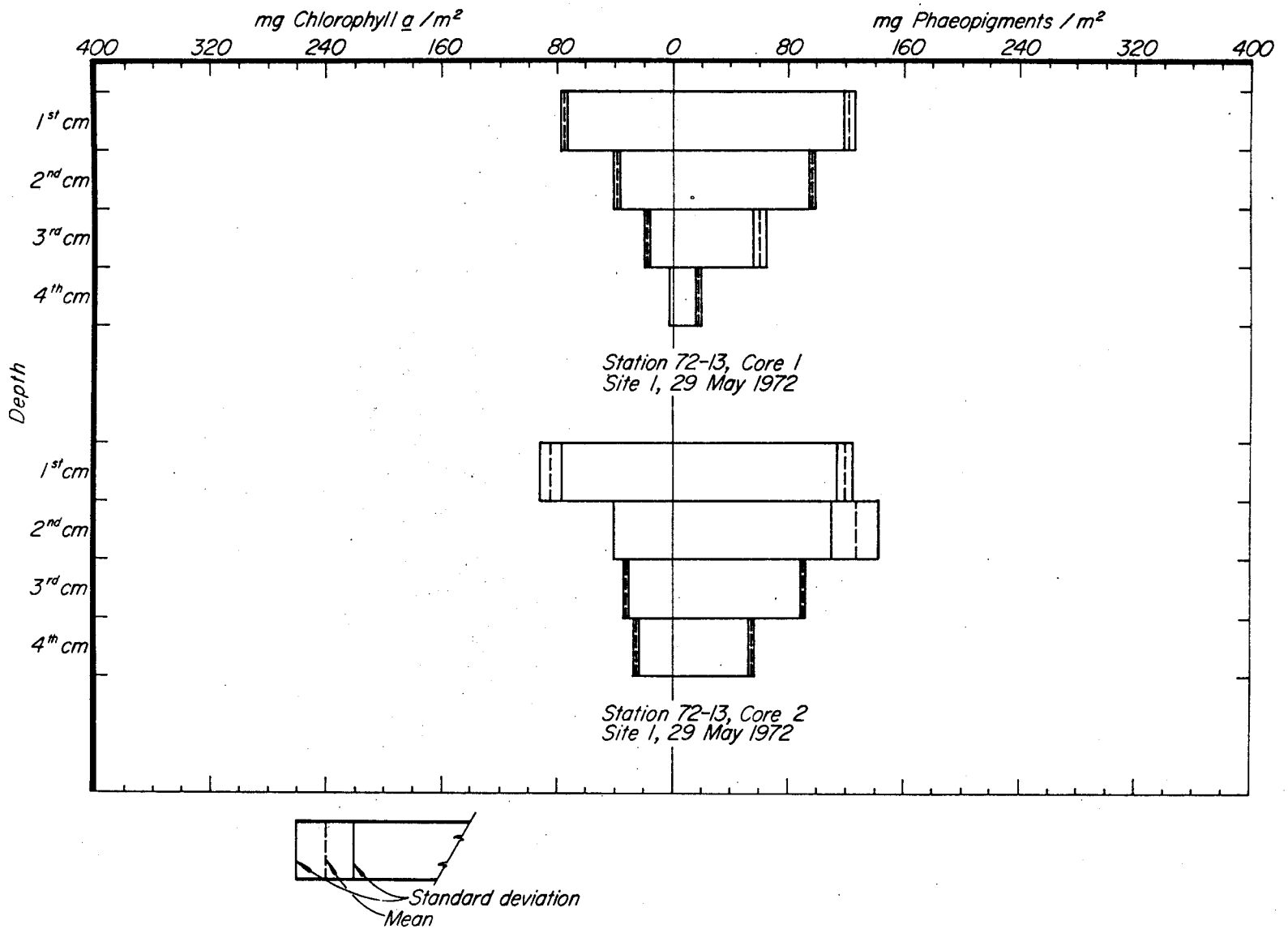

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-6, Core 1
Site 1, 19 April 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-6, Core 2
Site 1, 19 April 1972
Standard deviation
Mean

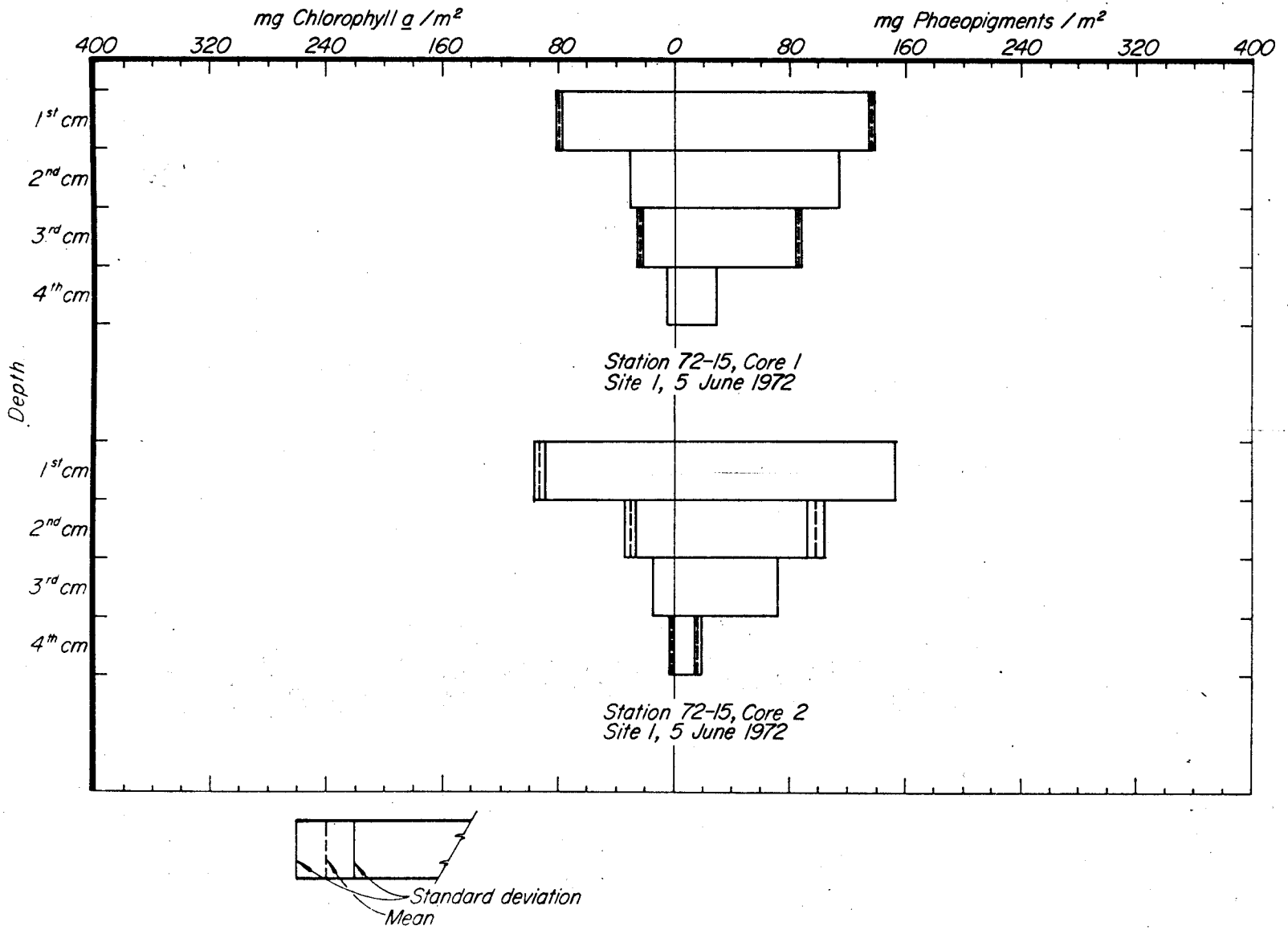

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-7, Core 1
Site 1, 20 April 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-7, Core 2
Site 1, 20 April 1972
Standard deviation
Mean

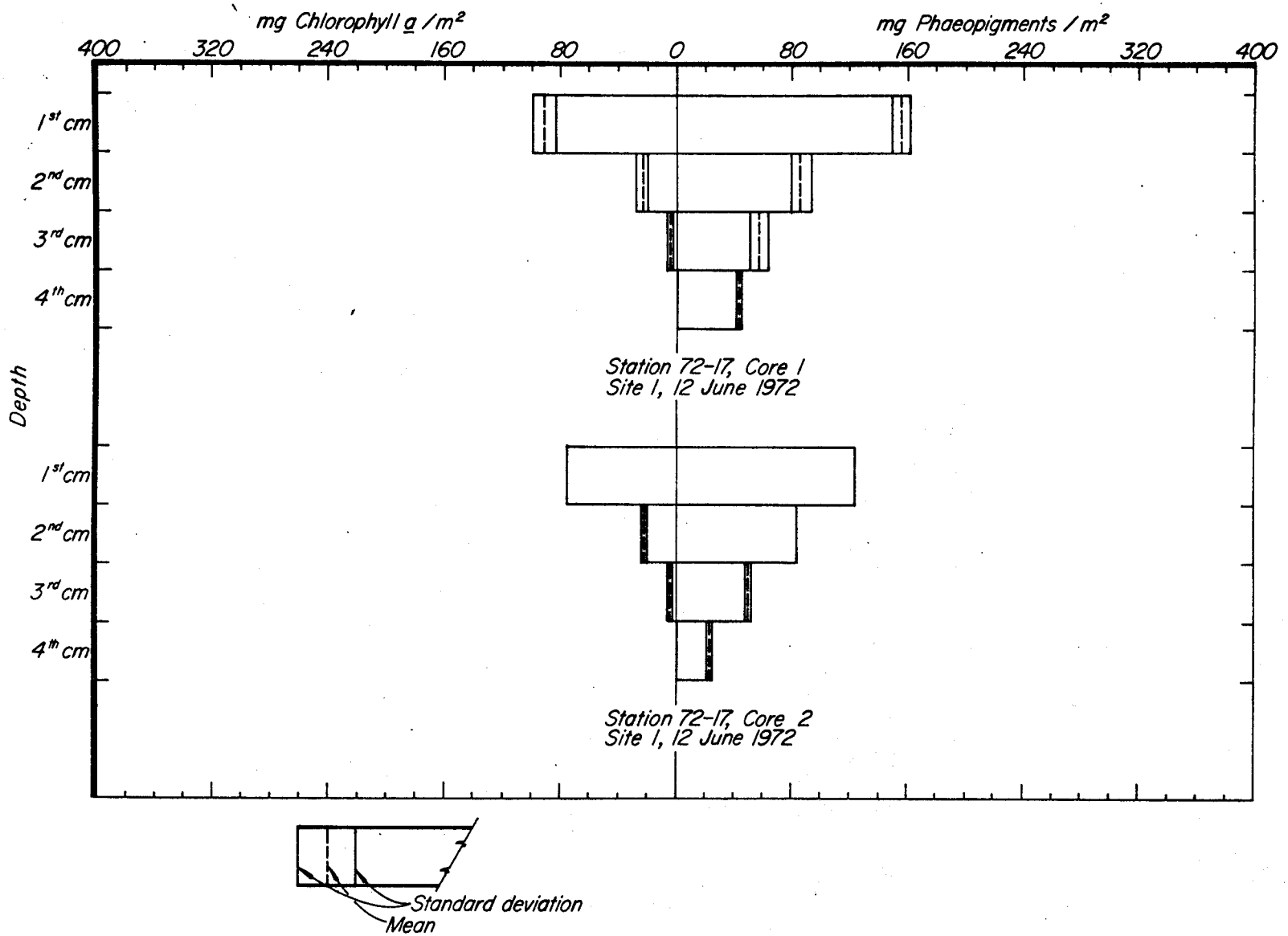

mg Chlorophyll a /m²
400
320
240
160
80
0
80
160
240
320
400
mg Phaeopigments /m²
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-8, Core 1
Site 1, 7 May 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-8, Core 2
Site 1, 7 May 1972
Standard deviation
Mean

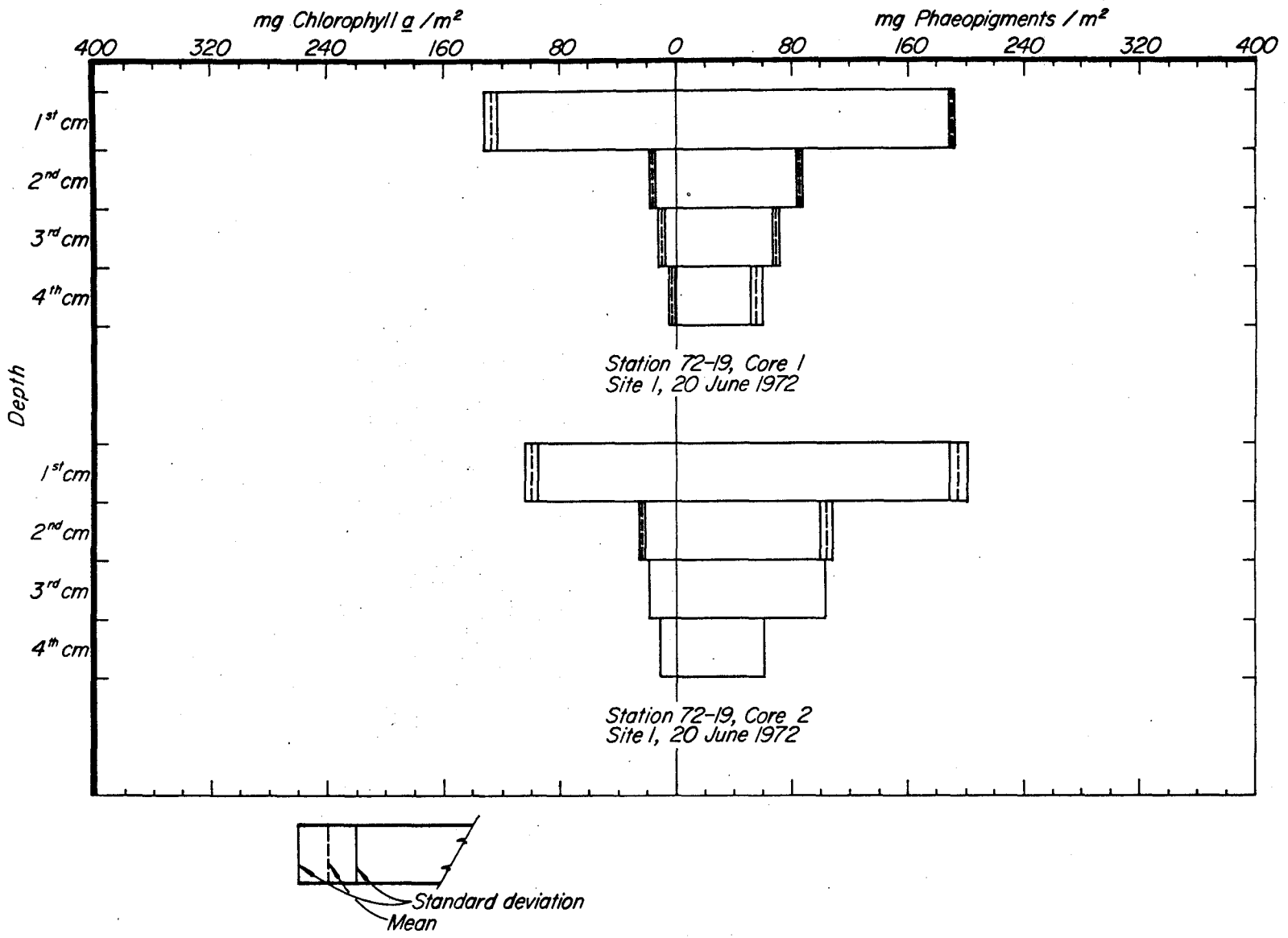

mg Chlorophyll a /m²
mg Phaeopigments /m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-10, Core 1
Site 1, 21 May 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-10, Core 2
Site 1, 21 May 1972
Standard deviation
Mean

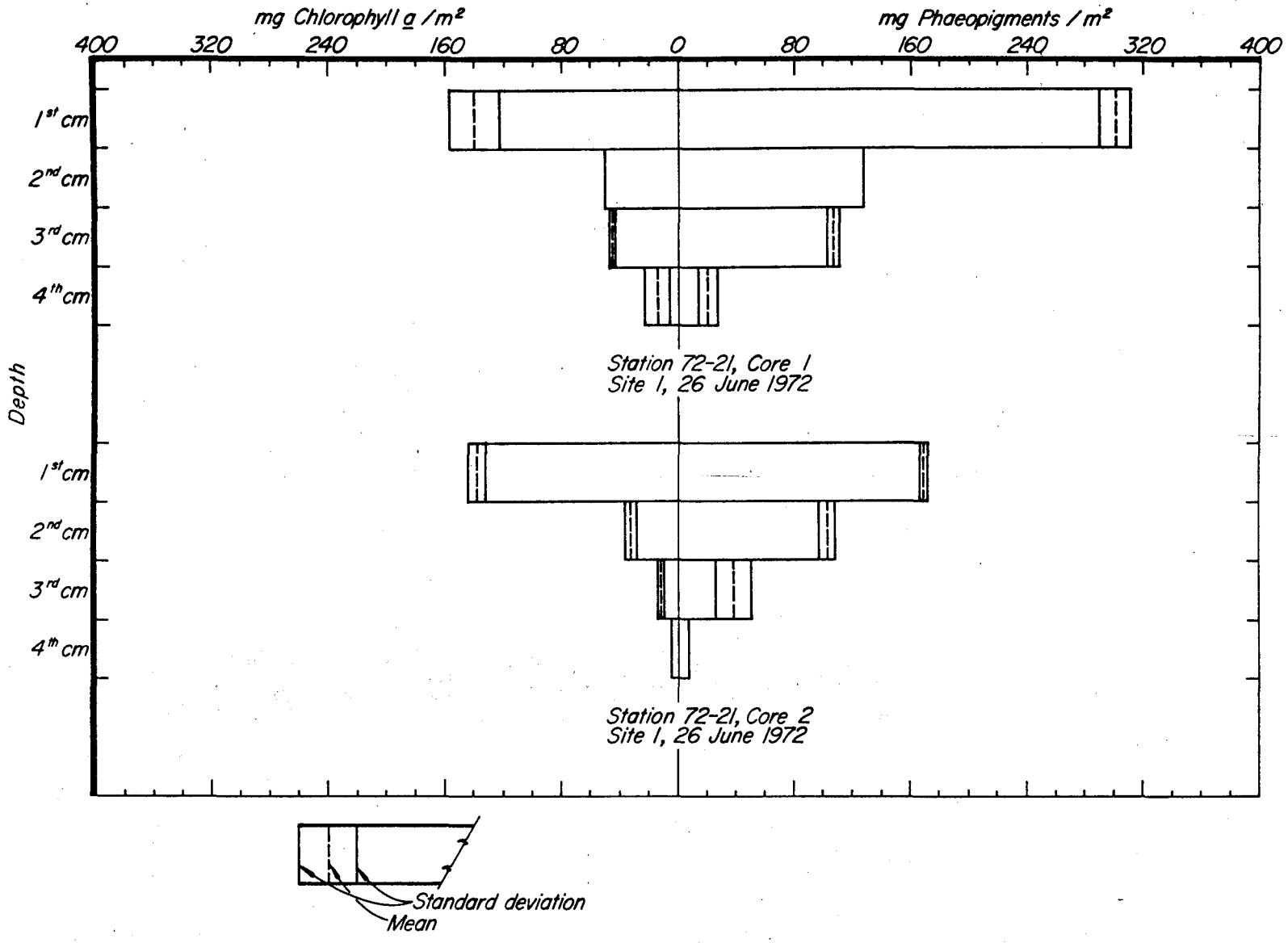

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-12, Core 1
Site 1, 27 May 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-12, Core 2
Site 1, 27 May 1972
Standard deviation
Mean

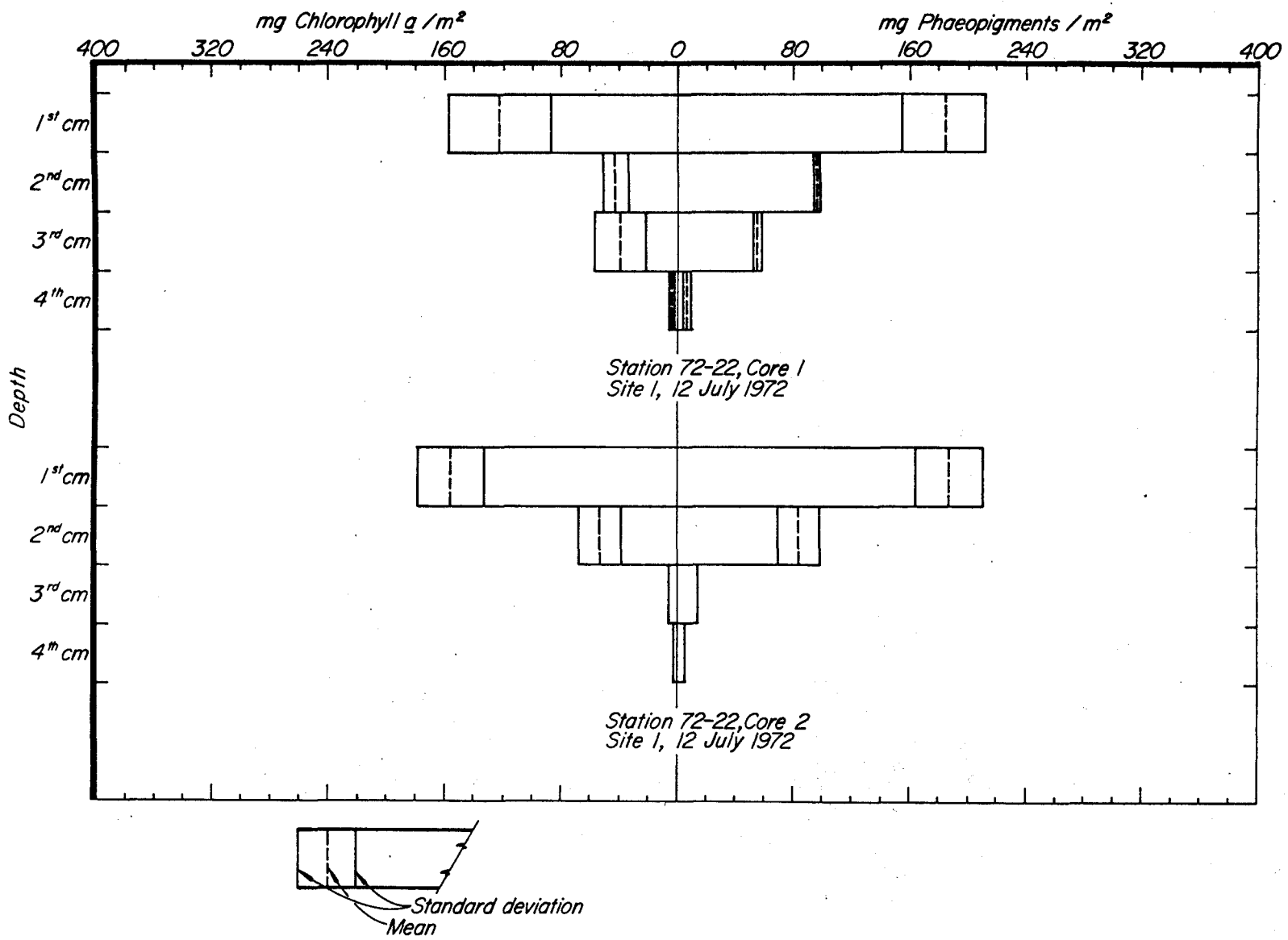

mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-13, Core 1
Site 1, 29 May 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-13, Core 2
Site 1, 29 May 1972
Standard deviation
Mean

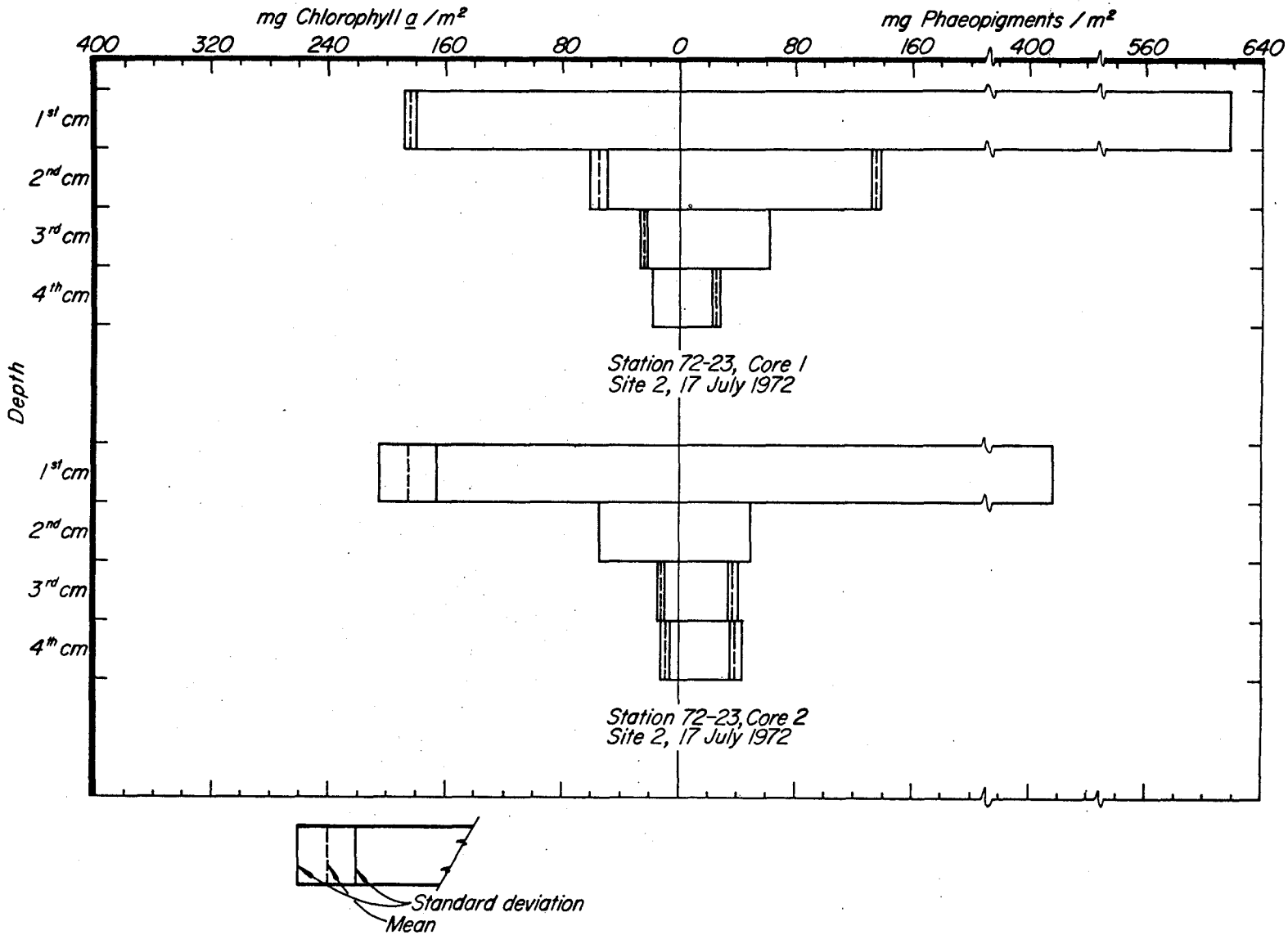

mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-15, Core 1
Site 1, 5 June 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-15, Core 2
Site 1, 5 June 1972
Standard deviation
Mean

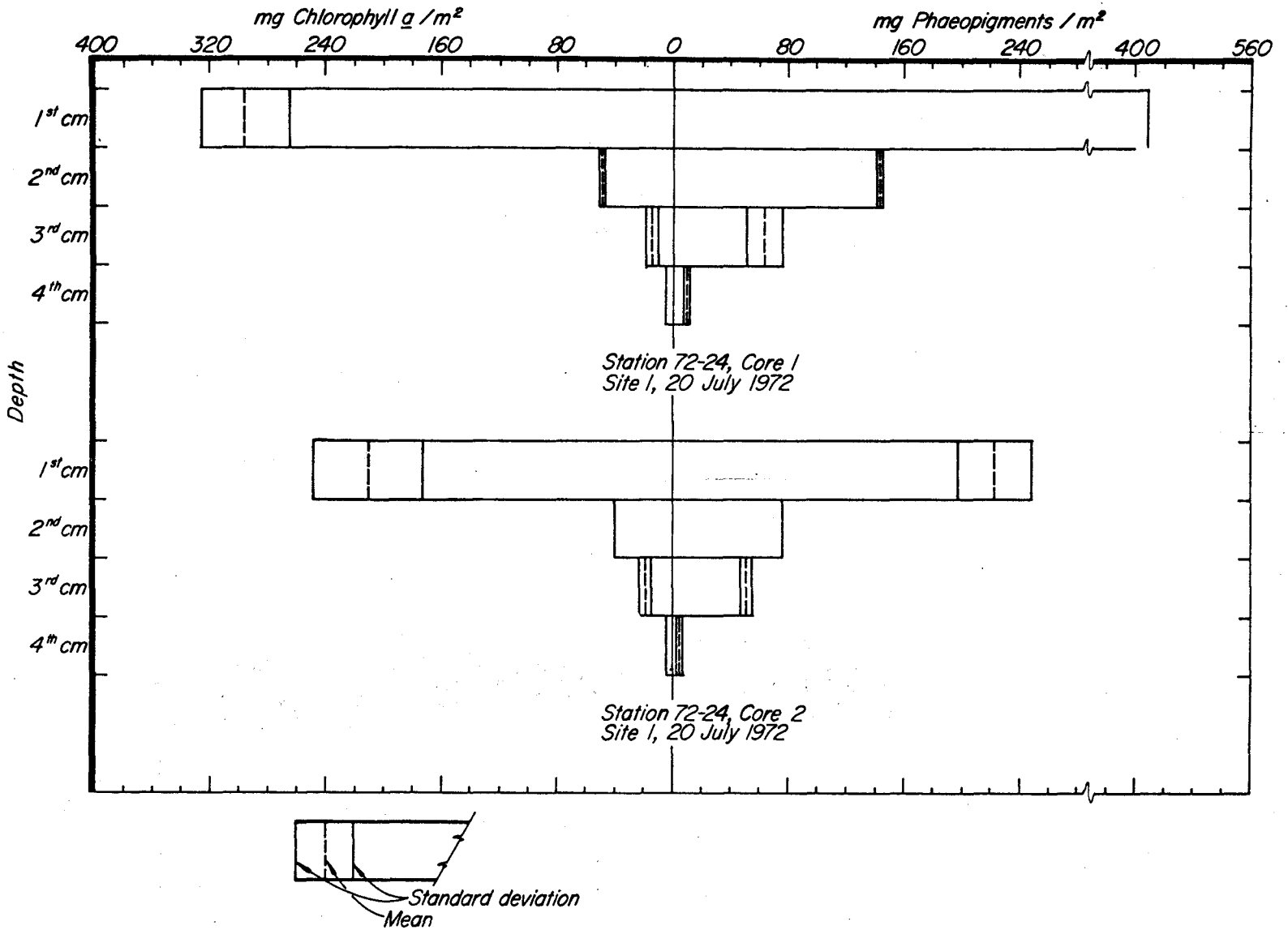

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-17, Core 1
Site 1, 12 June 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-17, Core 2
Site 1, 12 June 1972
Standard deviation
Mean

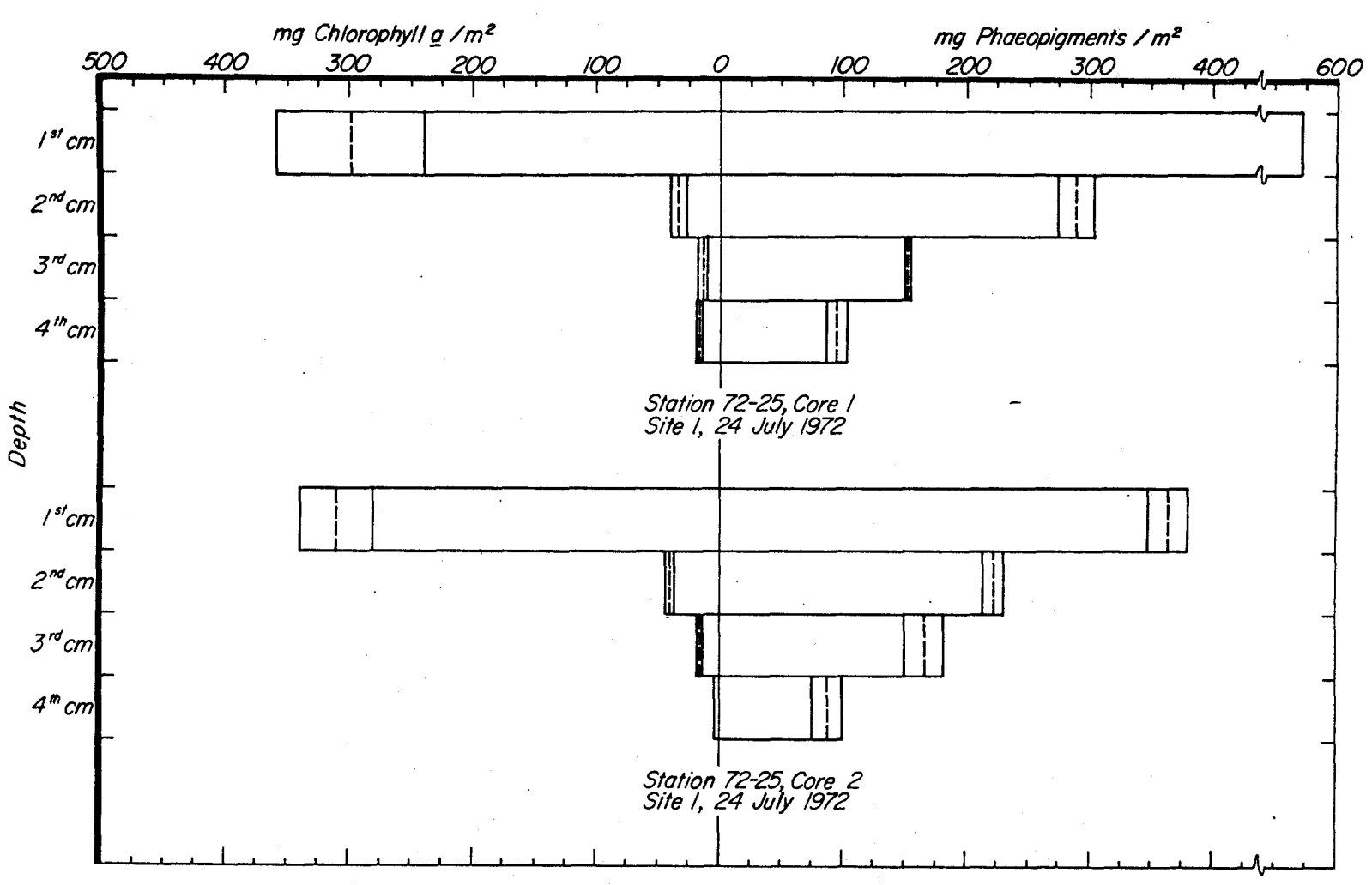

mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-19, Core 1
Site 1, 20 June 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-19, Core 2
Site 1, 20 June 1972
Standard deviation
Mean

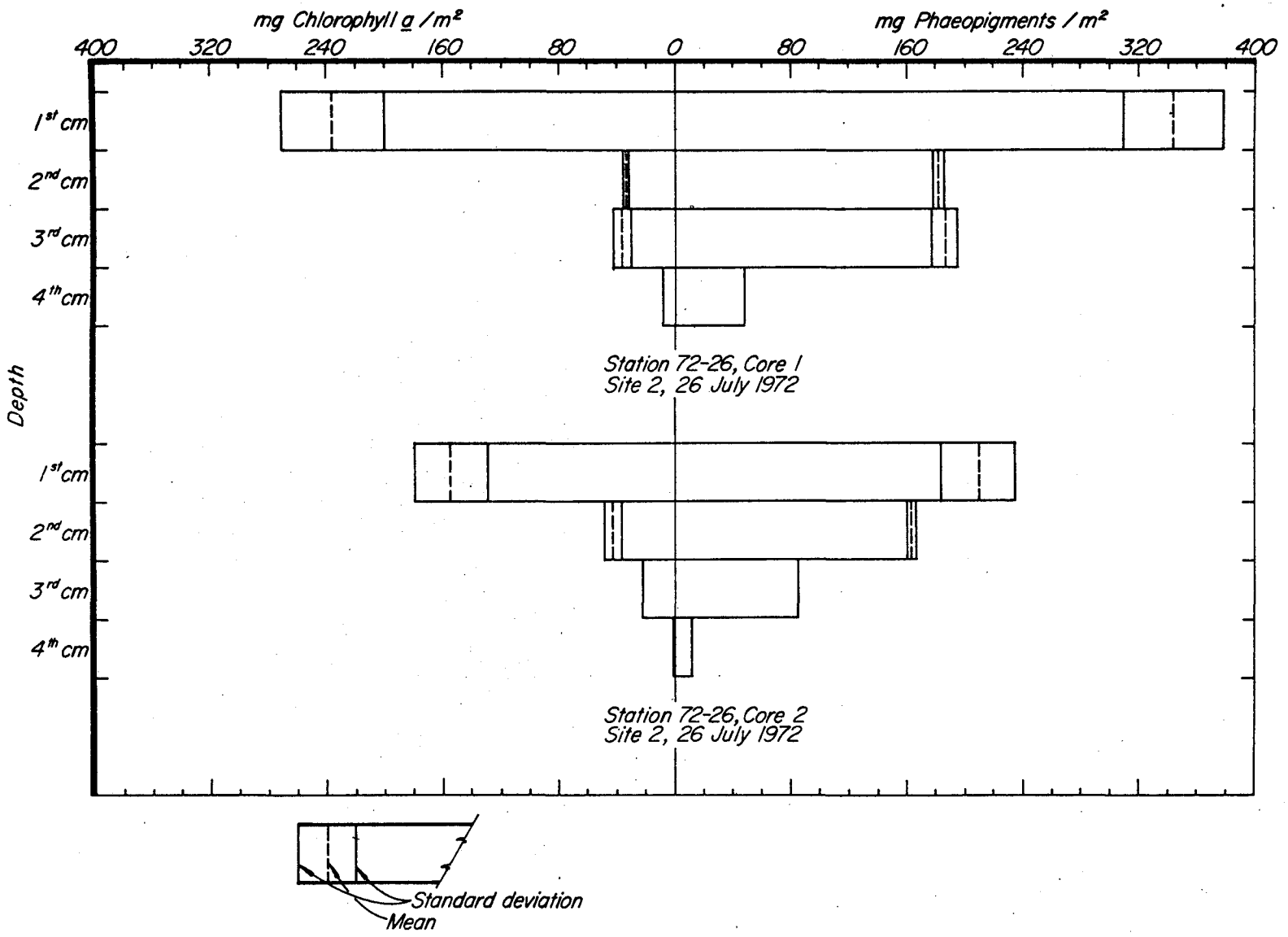

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-21, Core 1
Site 1, 26 June 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-21, Core 2
Site 1, 26 June 1972
Standard deviation
Mean

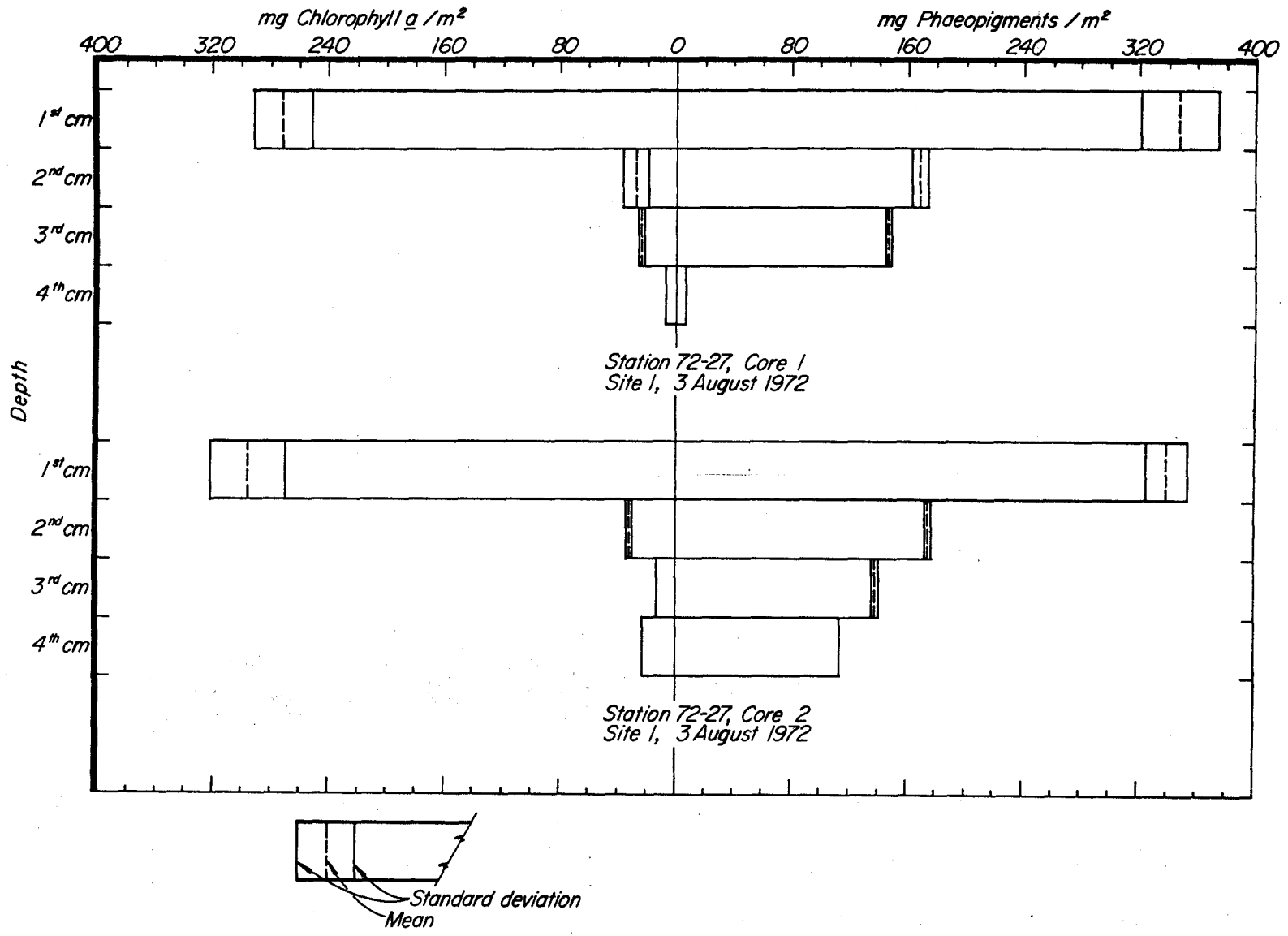

mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-22, Core 1
Site 1, 12 July 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-22, Core 2
Site 1, 12 July 1972
Standard deviation
Mean

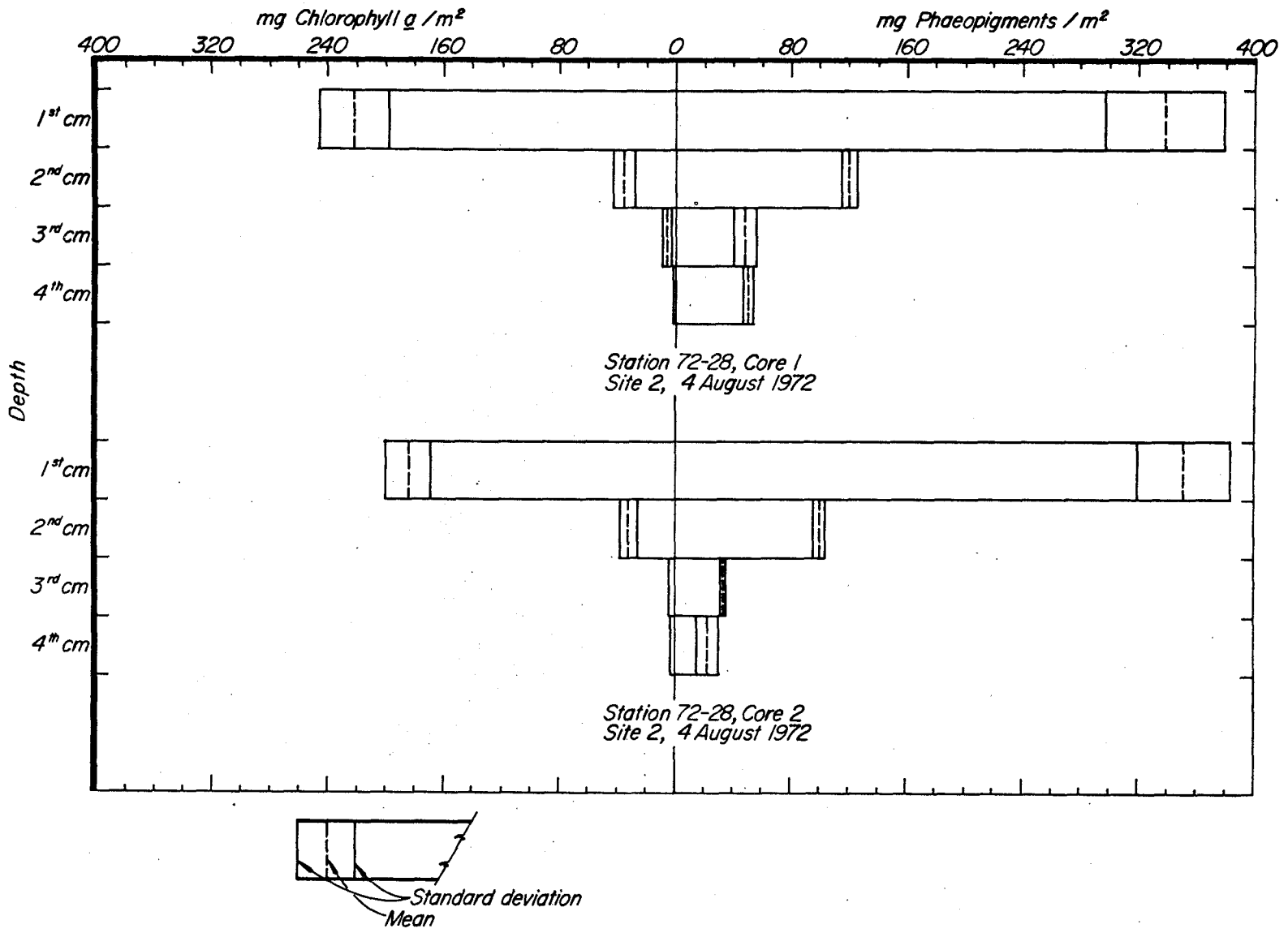

mg Chlorophyll a /m²
400
320
240
160
80
0
mg Phaeopigments / m²
80
160
400
560
640
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-23, Core 1
Site 2, 17 July 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-23, Core 2
Site 2, 17 July 1972
Standard deviation
Mean

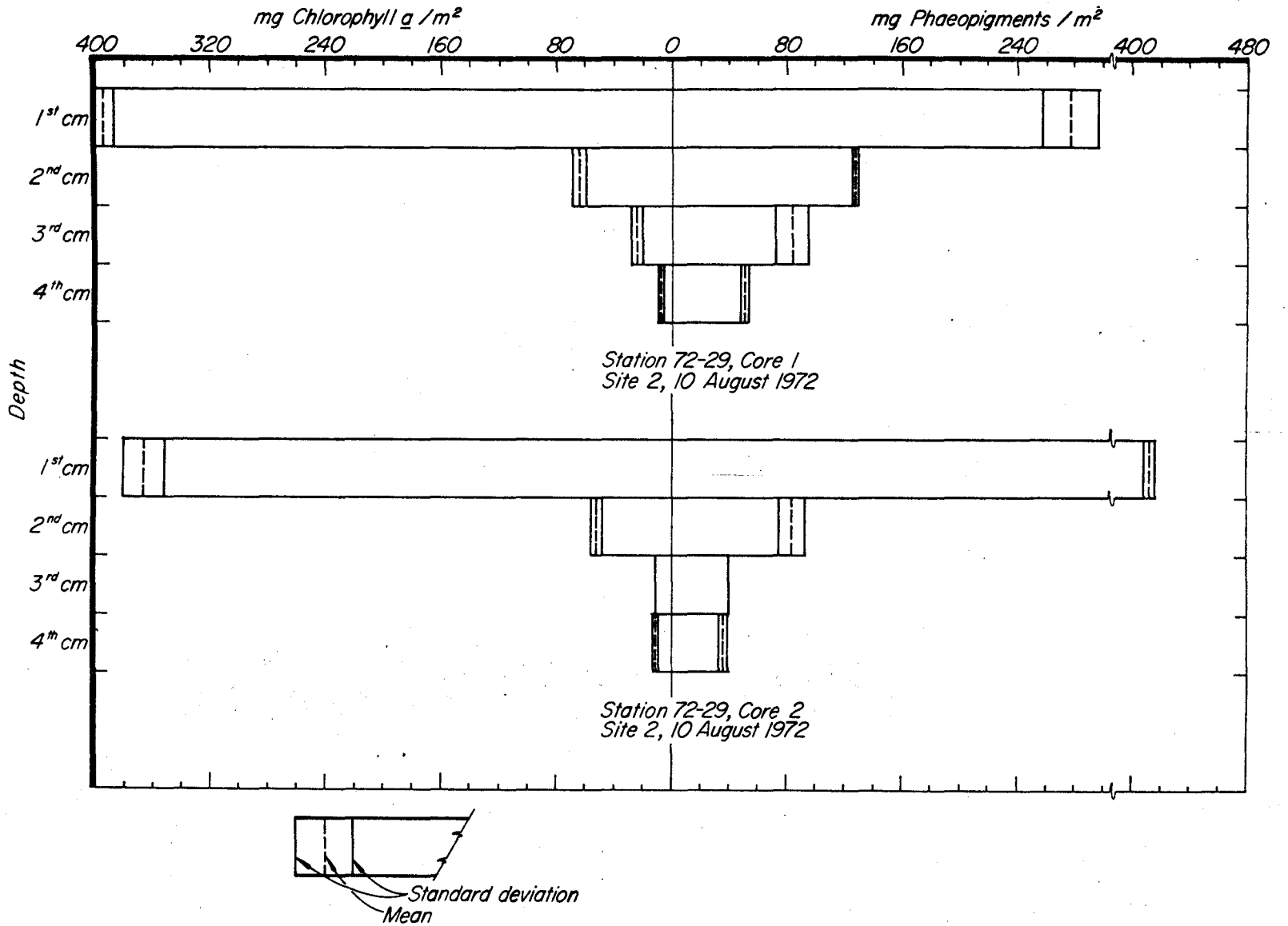

mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
400
560
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-24, Core 1
Site 1, 20 July 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-24, Core 2
Site 1, 20 July 1972
Standard deviation
Mean

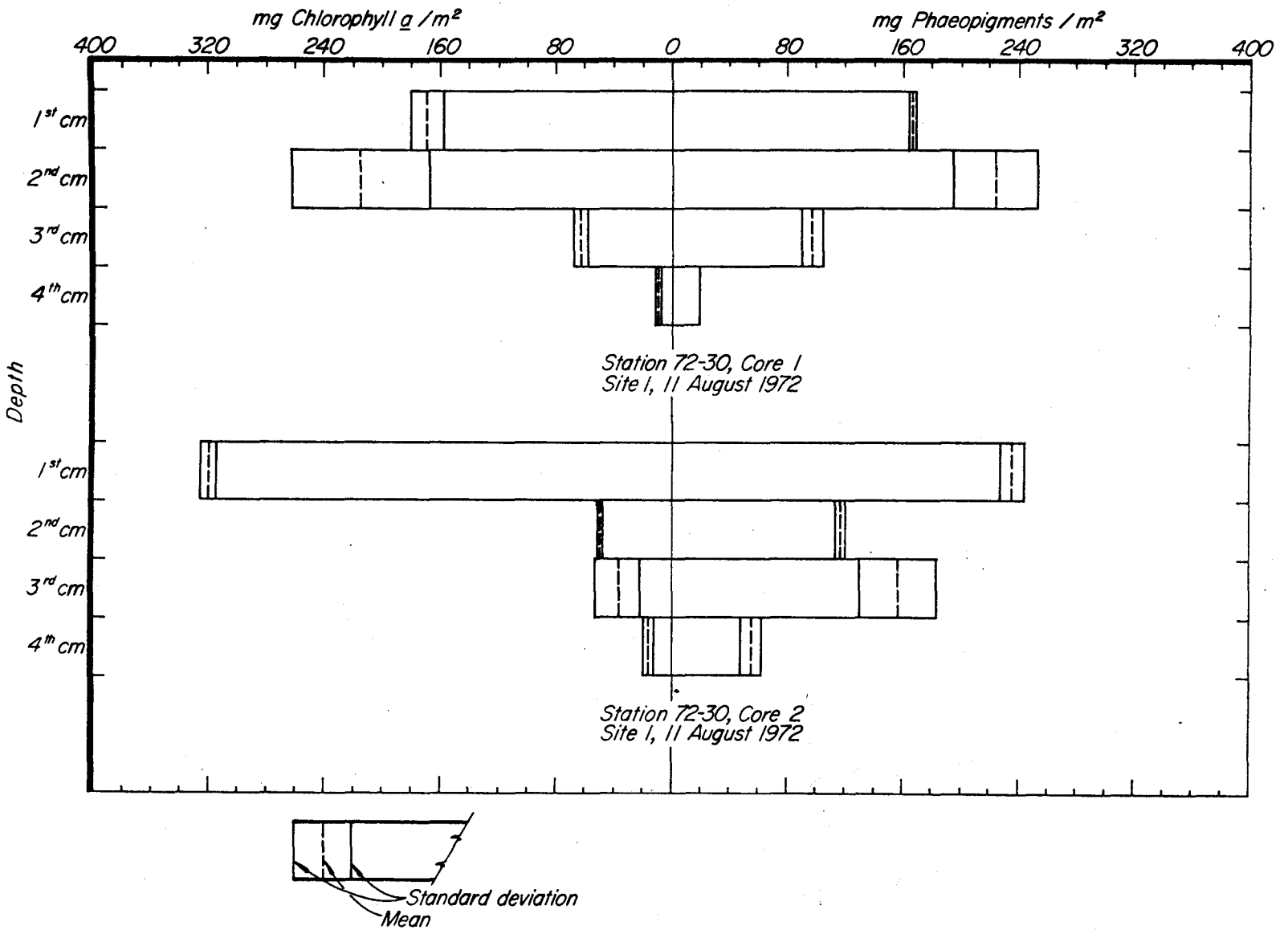

mg Chlorophyll a / m²
mg Phaeopigments / m²
500
400
300
200
100
0
100
200
300
400
600
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-25, Core 1
Site 1, 24 July 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-25, Core 2
Site 1, 24 July 1972
Standard deviation
Mean


mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-26, Core 1
Site 2, 26 July 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-26, Core 2
Site 2, 26 July 1972
Standard deviation
Mean


mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-27, Core 1
Site 1, 3 August 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-27, Core 2
Site 1, 3 August 1972
Standard deviation
Mean


mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-28, Core 1
Site 2, 4 August 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-28, Core 2
Site 2, 4 August 1972
Standard deviation
Mean


mg Chlorophyll a /m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
400
480
1st cm
2nd cm
3rd cm
4th cm
Depth
Station 72-29, Core 1
Site 2, 10 August 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-29, Core 2
Site 2, 10 August 1972
Standard deviation
Mean


mg Chlorophyll a / m²
mg Phaeopigments / m²
400
320
240
160
80
0
80
160
240
320
400
Depth
1st cm
2nd cm
3rd cm
4th cm
Station 72-30, Core 1
Site I, 11 August 1972
1st cm
2nd cm
3rd cm
4th cm
Station 72-30, Core 2
Site I, 11 August 1972
Standard deviation
Mean

APPENDIX D

Tabulated Data

Table 1a. Primary Productivity (mg C/m^2-hr), Site 1, 1972

Location	9 Feb	17 Mar	23 Mar	7 May	21 May	27 May
Bottom Ice (Epontic)	0.02*	0.06*		4.03	4.56	1.13
Water Column		0.04*		0.63	0.00	
Sediments	0.36		0.00	0.00	0.08	0.00
Location	**29 May**	**1 Jun**	**5 Jun**	**12 Jun**	**20 Jun**	**26 Jun**
Bottom Ice (Epontic Algae)	1.06		0.80			
Water Column	0.26		0.13	9.45	2.20	0.00
Sediments	0.17	0.45	0.00	0.53	0.82	1.86
Location	**20 July**	**24 July**	**3 Aug**	**11 Aug**	**16 Aug**	**21 Aug**
Water Column			2.21	17.63		15.32
Sediments	20.80	19.04	56.99	41.16	51.90	35.78

Table 1b. Primary Productivity (mg C/m^2-hr), Site 2, 1972

Location	17 Jul	26 Jul	4 Aug	10 Aug	15 Aug	22 Aug
Water Column	3.46	0.32	5.83	11.53		23.75
Sediments	14.51	16.92	33.04	2.35	20.72	32.75

Table 2a. Chlorophyll *a* and Phaeopigment Concentrations (mg/m^2), Upper 4 cm, Site 1, 1972

Location	8 Feb				9 Feb			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1*	2	1	2	1	2	1	2
1st cm	61.01	54.40	140.92	140.71	94.36	129.77	141.83	109.10
2nd cm	39.28	22.59	83.74	106.02	52.89	49.98	98.03	99.97
3rd cm	38.25	40.48	102.03	104.15	19.23	ND	63.97	ND
4th cm	0.00	2.58	63.27	70.14	6.84	5.72	29.06	11.30
Core 2								
1st cm								
2nd cm								
3rd cm								
4th cm								

Location	10 Feb				22 Mar			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	96.80	99.70	133.65	106.03	44.53	52.06	100.19	106.98
2nd cm	38.76	40.82	87.58	76.98	29.14	ND	59.88	ND
3rd cm	14.93	13.08	15.16	23.54	1.80	7.20	31.93	21.91
4th cm	4.72	4.36	21.76	24.52	4.66	4.67	12.06	13.16
Core 2								
1st cm	76.76	74.21	89.57	92.28	59.65	53.59	108.24	114.54
2nd cm	30.22	28.14	56.08	57.25	96.88	96.99	150.91	132.87
3rd cm	36.84	37.49	48.75	47.69	5.85	ND	4.73	ND
4th cm	3.75	0.00	19.91	22.78	1.67	ND	8.14	ND

*subsample number

Table 2a. continued

Location	19 Apr				20 Apr			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	48.49	51.52	121.24	112.39	49.88		112.13	
2nd cm	35.58	34.45	108.06	94.92	42.28		95.10	
3rd cm	50.17	52.32	134.60	137.28	20.21		50.26	
4th cm	19.10	34.34	56.53	92.46	11.36		50.39	
Core 2								
1st cm	72.10	51.08	237.72	201.50	59.23		136.61	
2nd cm	34.31	37.60	118.46	109.27	25.87		81.29	
3rd cm	17.78	21.54	94.30	98.02	4.63		14.19	
4th cm	15.86	19.48	69.20	67.04	0.98		10.34	

Location	7 May				21 May			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	15.28	16.74	58.99	59.23	50.29	58.03	88.03	89.61
2nd cm	21.57	25.94	79.65	86.60	24.93	22.03	66.14	63.57
3rd cm	14.85	9.95	64.89	76.88	12.53	11.64	38.17	36.56
4th cm	9.14	10.24	47.60	43.57	9.71	7.76	18.18	20.13
Core 2								
1st cm	53.38	50.13	118.18	113.32	69.70	61.78	91.94	88.92
2nd cm	22.80	22.53	89.54	79.48	26.06	ND	61.72	ND
3rd cm	10.55	13.79	71.08	65.25	15.00	14.32	41.03	41.90
4th cm	9.60	9.26	56.70	60.55	7.34	5.67	16.99	18.19

Table 2a. continued

Location	27 May				29 May			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	66.07	69.80	24.53	33.52	77.95	73.80	124.98	117.99
2nd cm	24.52	33.52	102.93	97.39	36.31	40.38	95.23	96.78
3rd cm	28.65	28.68	85.76	92.69	19.85	18.77	55.45	64.92
4th cm	16.85	13.35	58.93	43.22	2.61	2.09	18.13	16.14
Core 2								
1st cm	87.95	89.13	133.34	150.61	77.30	91.41	119.28	130.53
2nd cm	33.72	29.49	101.30	102.29	40.81	40.83	149.76	114.49
3rd cm	11.82	21.41	86.73	49.68	32.20	33.84	89.20	90.08
4th cm	0.00	2.44	27.44	27.81	23.64	26.38	53.46	56.72

Location	5 Jun				12 Jun			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	79.06	80.81	136.57	136.61	83.56	99.49	161.90	148.28
2nd cm	30.09	ND	114.18	ND	28.00	19.40	78.60	93.25
3rd cm	24.49	23.52	85.91	85.18	2.73	7.66	50.59	63.81
4th cm	4.49	ND	29.47	ND	0.00	0.00	42.83	44.58
Core 2								
1st cm	89.42	34.55	172.01	131.94	75.19	ND	143.79	ND
2nd cm	34.45	26.41	103.76	92.71	30.49	30.21	83.12	ND
3rd cm	14.29	ND	72.28	ND	5.73	5.26	50.77	48.38
4th cm	1.63	2.46	14.35	18.61	1.29	0.00	24.10	21.32

Table 2a. continued

Location	20 Jun				26 Jun			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	122.19	132.29	209.59	209.64	122.33	156.54	291.44	312.60
2nd cm	18.82	16.53	85.25	84.73	49.29	ND	128.32	ND
3rd cm	12.24	10.48	70.97	65.54	46.30	44.58	111.28	103.64
4th cm	1.69	5.17	50.93	59.58	5.23	22.39	28.99	14.18
Core 2								
1st cm	96.29	105.11	201.31	188.43	145.31	131.21	168.00	172.35
2nd cm	23.71	25.22	107.55	99.49	28.27	35.74	97.80	108.54
3rd cm	19.57	ND	102.03	ND	10.14	14.08	25.84	50.25
4th cm	12.40	ND	60.40	ND	4.13	ND	7.43	ND

Location	12 Jul*				20 Jul			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	158.66	86.83	213.81	155.83	326.49	266.17	458.87	359.13
2nd cm	34.58	51.58	95.11	97.78	49.96	49.75	144.74	143.95
3rd cm	22.48	57.03	52.97	57.03	9.51	19.69	52.15	76.85
4th cm	0.58	4.87	12.56	1.93	4.91	3.91	11.70	8.42
Core 2								
1st cm	179.45	133.71	211.58	165.28	180.37	240.84	249.95	198.63
2nd cm	67.49	39.14	98.70	70.47	39.25	ND	77.54	ND
3rd cm	4.35	ND	14.94	ND	6.40	12.36	14.54	0.00
4th cm	2.87	2.72	7.68	2.98	2.74	3.59	7.35	3.10

*part of the sample was lost due to difficulty in sampling the *Amphipleura rutilans* mat.

Table 2a. continued

Location	24 Jul				3 Aug			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	360.94	241.46	446.13	697.94	251.32	295.45	320.32	375.87
2nd cm	26.87	40.93	304.34	276.43	36.31	19.29	163.69	174.85
3rd cm	18.19	10.55	151.46	155.43	22.53	25.46	144.82	147.59
4th cm	19.18	15.29	102.39	86.20	7.89	ND	7.05	ND
Core 2								
1st cm	281.75	342.36	350.23	388.71	270.86	376.93	322.75	351.42
2nd cm	38.52	45.27	213.82	230.57	31.99	33.22	177.22	173.37
3rd cm	17.63	16.48	150.91	181.94	13.52	ND	139.94	ND
4th cm	0.00	9.34	98.43	75.73	23.67	ND	134.26	ND

Location	11 Aug				16 Aug			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	180.63	158.76	165.26	168.28	310.33	328.75	242.73	261.77
2nd cm	168.02	263.18	194.48	253.63				
3rd cm	69.29	58.00	105.35	89.78				
4th cm	10.58	10.44	20.00	18.81				
Core 2								
1st cm	315.53	326.47	228.22	245.75	250.35	262.78	187.37	215.82
2nd cm	49.85	50.94	120.35	114.31				
3rd cm	52.02	21.46	130.05	184.23				
4th cm	11.52	19.11	47.57	62.45				

Table 2a. continued

Location	21 Aug			
	Chl *a*		Phaeo	
Core 1	1	2	1	2
1st cm	213.43	227.85	214.72	246.35
2nd cm				
3rd cm				
4th cm				
Core 2				
1st cm	295.73	263.83	197.33	240.61
2nd cm				
3rd cm				
4th cm				

Table 2b. Chlorophyll *a* and Phaeopigment Concentrations (mg/m^2), Upper 4 cm, Site 2, 1972.

Location	17 Jul				26 Jul			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	181.05	187.62	601.74	636.14	200.94	271.39	310.86	379.84
2nd cm	50.08	61.46	137.17	132.87	37.18	31.83	186.09	178.47
3rd cm	27.52	22.22	63.88	61.72	30.64	42.66	195.79	178.52
4th cm	18.29	18.15	24.80	27.03	10.32	ND	55.72	ND
Core 2								
1st cm	185.12	205.84	473.48	361.42	155.67	216.29	184.36	235.69
2nd cm	53.87	ND	100.06	ND	48.78	37.91	166.88	161.45
3rd cm	9.33	14.35	42.04	34.93	22.60	ND	85.29	ND
4th cm	14.19	5.43	43.43	34.85	0.00	ND	11.56	ND

Location	4 Aug				10 Aug			
	Chl *a*		Phaeo		Chl *a*		Phaeo	
Core 1	1	2	1	2	1	2	1	2
1st cm	248.35	197.38	296.73	379.75	389.83	402.34	258.64	296.79
2nd cm	27.35	42.89	116.50	126.89	59.31	70.96	126.15	126.66
3rd cm	9.84	1.59	41.63	57.84	21.30	30.42	94.14	72.09
4th cm	0.00	0.00	47.97	54.85	8.85	9.85	32.68	28.38
Core 2								
1st cm	168.65	181.32	319.47	382.03	381.89	353.94	406.75	413.33
2nd cm	37.61	25.44	105.56	96.79	56.54	49.40	92.61	47.08
3rd cm	7.80	7.68	32.94	33.68	11.38	ND	38.25	ND
4th cm	2.43	0.00	16.87	32.61	11.17	13.44	39.38	33.64

Table 2b. continued

Location	15 Aug			
	Chl *a*		Phaeo	
Core 1	1	2	1	2
1st cm	218.73	232.37	185.46	221.33
2nd cm				
3rd cm				
4th cm				
Core 2				
1st cm	259.39	253.14	196.26	214.73
2nd cm				
3rd cm				
4th cm				

22 Aug

Chl *a*		Phaeo	
1	2	1	2
271.91	252.33	171.02	198.87
219.36	240.64	140.37	135.26

Table 3. Chlorophyll *a* and Phaeopigments (mg/m^2) upper 1 cm only, 1972.

Location	9 May 16 Cores taken in 1 m^2		25 May 16 Cores taken 21 m along a transect 16m long	
	Chl *a*	Phaeo	Chl *a*	Phaeo
Core 1	39.56	86.04	14.68	44.15
Core 2	96.93	115.32	38.31	90.18
Core 3	40.18	85.06	54.76	129.58
Core 4	93.82	147.30	46.14	112.10
Core 5	36.02	63.18	41.77	92.56
Core 6	35.57	108.91	45.81	124.34
Core 7	47.18	109.38	31.48	94.18
Core 8	84.03	124.70	23.77	81.84
Core 9	35.54	90.84	50.14	131.48
Core 10	60.51	97.76	66.58	135.29
Core 11	36.31	81.16	52.73	124.07
Core 12	48.49	111.84	36.47	115.63
Core 13	48.34	106.30	39.46	112.20
Core 14	37.77	78.05	69.18	110.39
Core 15	43.22	101.37	39.58	111.30
Core 16	35.18	95.16	49.62	125.73

Table 4. Weather, Snow and Ice Conditions, 1972

Date	Sky Conditions	Wind Speed (mph)	Wind Direction
8 Feb	Clear		
9 Feb	Overcast		
10 Feb	Clear		
22 Mar	Clear	1-2	variable
23 Mar	Clear	5-10	NE
19 Apr	Clear	10	ENE
20 Apr	Clear	5	ENE
7 May	Clear	calm	
9 May	Overcast		
21 May	Partly cloudy	10-15	NE
25 May	Clear	1-2	variable
27 May	Clear	10-20	ENE
29 May	Fog		
1 Jun	Cloudy, snow flurries	10-15	ENE
5 Jun	Cloudy	calm	
8 Jun	Clear		
12 Jun	Clear	calm	
15 Jun			
20 Jun	Overcast, Fog	10-15	variable
22 Jun	Overcast	10-15	NE
26 Jun	Clear	10-15	NE
12 Jul	Clear	1-2	variable
17 Jul	Foggy	calm	
20 Jul			

Air Temp. °C	Snow Depth (cm)	Ice Thickness (cm)
-21	5	116
-18	5	128
-31	5	116
-20	8	170
-15	15	170
-12	15	165
-15	15-20	165
1	5-7	165
-1	5	180
-5	2	176
	3	170
0	0	160
-7	0	160
-7	0	160
1	0	160
-7	0	155
3.5	0	ca. 155
	0	ca. 140
1	0	ca. 135
3	0	ca. 115
	0	ca. 100
10	0	0
10	0	0
+3	0	0

Table 4. continued

Date	Sky Conditions	Wind Speed (mph)	Wind Direction
24 Jul	Clear	10-15	NE
26 Jul	Cloudy, Fog	5-10	NE
2 Aug	Clear	calm	
4 Aug	Clear	calm	
5 Aug	Overcast	calm	
10 Aug	Cloudy, Rain	10-15	NW
11 Aug	Cloudy	10-15	NW
15 Aug			
16 Aug			
21 Aug	Scattered Fog	calm	
22 Aug	Fog	light	variable

Air Temp. °C	Snow Depth (cm)	Ice Thickness (cm)
4	0	0
0	0	0
8	0	0
10	0	0
7	0	0
	0	0
6	0	0
6	0	0
	0	0
9	0	0
11	0	0

Table 5. Sea Water Temperatures (Surface only) (°C), 1972

8 Feb	-2	15 Jun	-2
9 Feb	-2	20 Jun	-2
10 Feb	-2	22 Jun	-2
22 Mar	-2	26 Jun	-2
23 Mar	-2	12 Jul	0
19 Apr	-2	17 Jul (2)	1
20 Apr	-2	20 Jul	0.5
7 May	-2	24 Jul	1
9 May	-2	26 Jul (2)	-1
21 May	-2	3 Aug	5
25 May	-2	4 Aug (2)	6
27 May	-2	5 Aug (2)	6
29 May	-2	10 Aug (2)	7
1 Jun	-2	11 Aug	7
5 Jun	-2	15 Aug (2)	7
8 Jun	-2	16 Aug	7
12 Jun	-2	21 Aug	8
		22 Aug (2)	8

(2) indicates site 2

Table 6. Salinity (°/₀₀), 1972

Location	9 Feb	10 Feb	22 Mar	23 Mar	19 Apr	20 Apr	7 May
0 m	32.02	35.31	34.09		33.68		32.28
5 m			33.36		33.79	33.75	32.68
Interstitial water							

Location	21 May	27 May	29 May	5 Jun	8 Jun	12 Jun	15 Jun
0 m	32.73	33.02	32.94	32.59	30.36	27.39	4.76
5 m	33.05			33.18	33.64	32.85	32.62
Interstitial water		35.09	35.36	34.36		33.87	

Location	20 Jun	22 Jun	26 Jun	12 Jul	17 Jul (2)	20 Jul	24 Jul
0 m	1.92	2.06	29.42	30.65	25.63	24.79	30.12
5 m	32.42	29.05	31.62	29.70	29.15	27.15	31.35
Interstitial water	36.37		33.93	32.24	29.80	29.85	31.60

(2) indicates site 2

Table 6. continued

Location	26 Jul (2)	3 Aug	4 Aug (2)	5 Aug (2)	10 Aug (2)	11 Aug	15 Aug (2)
0 m	31.86	29.07	28.80	28.86	28.85	29.25	
5 m	32.46	29.52	29.24	29.44	29.25	29.43	30.17
Interstitial water	32.32	30.71	31.32	ND	31.34	30.24	31.09

Location	16 Aug	21 Aug	22 Aug (2)
0 m		30.35	30.31
5 m	30.32	30.34	30.31
Interstitial water	31.19	31.37	32.05

(2) indicates site 2

Table 7. Nutrient Concentrations (µg-at/ℓ), 1972

Date	Location	$NO_3^- + NO_2^-$
9 Feb	Water, 5 m	4.7
10 Feb	Water, 5 m	6.4
22 Mar	Water, 5 m	9.2
19 Apr	Water, 5 m	8.9
20 Apr	Water, 5 m	7.2
7 May	Water, 5 m	6.8
21 May	Water, 5 m	4.2
25 May	Interstitial Water	6.5
27 May	Interstitial Water	13.4
29 May	Water, 5 m	12.6
	Interstitial Water	16.2
5 Jun	Water, 5 m	ND
	Interstitial Water	14.0

NH_4^+	$PO_4^{\equiv}$	SiO_3
2.3	1.4	ND
3.6	1.4	22.3
7.1	1.7	35.1
1.2	ND	ND
1.0	ND	ND
1.6	1.0	25.7
1.1	0.9	12.4
28.0	ND	109.0
35.5	0.3	56.90
1.8	2.0	52.6
25.5	0.5	78.0
2.5	1.6	4.0
38.6	0.7	>100.0

Table 7. continued

Date	Location	$NO_3^- + NO_2^-$	NH_4^+
8 Jun	Water, 5 m	5.8	1.9
12 Jun	Water, 5 m	2.3	0.9
	Interstitial Water	16.3	24.4
20 Jun	Water, 5 m	1.7	1.5
	Interstitial Water	5.5	51.9
22 Jun	Water, 4.5 m	1.0	1.3
26 Jun	Water, 5 m	0.6	1.9
	Interstitial Water	4.5	47.3
12 Jul	Water, 5 m	0.4	1.5
	Interstitial Water	3.7	61.0
17 Jul (2)	Water, 5 m	0.4	1.0
	Interstitial Water	1.4	32.5
20 Jul	Water, 5 m	ND	ND
	Interstitial Water	1.72	39.8
24 Jul	Water, 5 m	0.5	0.6
	Interstitial Water	1.4	34.4

(2) indicates site 2

$PO_4^{\equiv}$	SiO_3
1.5	31.7
0.9	24.3
0.8	>100.0
1.0	12.8
1.1	51.9
0.9	8.2
0.8	6.2
0.9	68.0
0.7	9.8
ND	ND
0.4	8.2
0.8	76.0
0.4	8.0
0.8	78.7
0.6	11.9
1.3	63.9

Table 7. continued

Date	Location	$NO_3^- + NO_2^-$
26 Jul (2)	Water, 5 m	5.5
	Interstitial Water	3.5
3 Aug	Water, 5 m	1.5
	Interstitial Water	2.9
4 Aug (2)	Water, 5 m	0.2
	Interstitial Water	3.2
10 Aug (2)	Water, 5 m	0.2
	Interstitial Water	2.0
11 Aug	Water, 5 m	0.4
	Interstitial Water	1.8
15 Aug (2)	Interstitial Water	1.94
16 Aug	Interstitial Water	6.7
21 Aug	Water, 5 m	0.3
	Interstitial Water	4.3
22 Aug (2)	Water, 5 m	0.4
	Interstitial Water	0.8

(2) indicates site 2

NH_4^+	$PO_4^{\equiv}$	SiO_3
1.6	2.6	19.0
41.6	0.8	68.2
0.5	0.6	7.0
40.2	2.8	93.2
0.4	0.4	5.9
30.8	1.4	98.4
0.4	0.5	7.5
32.8	0.7	>100.0
0.4	0.7	7.3
31.0	1.6	>100.0
30.0	0.9	>100.0
39.9	ND	>100.0
0.4	0.5	10.9
25.6	1.4	>100.0
0.8	0.6	10.2
24.8	1.1	>100.0

Table 8. ΣCO_2 (meq/l), 1972

Location	9 Feb	13 Mar	19 Apr	7 May	9 May	25 May	27 May
6 m	2.32	2.30	2.32	1.82	2.54		
Interstitial Water						2.62	2.77

Location	29 May	5 Jun	12 Jun	20 Jun	26 Jun	12 Jul	17 Jul (2)
6 m		2.18	2.10	2.09	2.51	1.90	2.08
Interstitial Water	3.12	2.41	4.12	3.07	3.49	2.52	3.12

Location	20 Jul	24 Jul	26 Jul (2)	3 Aug	4 Aug (2)	11 Aug (2)	15 Aug
6 m	1.61	1.91	2.20	1.89	1.91	1.91	1.88
Interstitial Water	2.89	3.62	3.25	2.85	2.90	3.18	3.16

(2) indicates site 2

Table 8. continued

Location	16 Aug (2)	21 Aug
6 m	1.77	1.98
Interstitial Water		3.00

(2) indicates site 2

22 Aug (2)

2.12

3.49

Table 9. Light (Lux), 1972

Location	7 May	9 May	21 May	27 May	29 May	1 Jun	12 Jun
Above Surface	22,000	33,000	13,750	35,000	33,000	33,000	44,000
Ice-Water Interface	175	175	262	1,400	2,800	526	2,800
Sediment-Water Interface	900	88	700	175	700	526	1,400

Location	26 Jun	12 Jul	17 Jul (2)	20 Jul	24 Jul	3 Aug	4 Aug (2)
Above Surface	66,000	88,000	33,000	22,000	16,500	66,000	27,500
Ice-Water Interface	11,000						
0 m			33,000		16,500	9,625	8,250
Sediment-Water Interface	2,000	44,000	5,500	2,800	13,500	9,625	4,150

Location	5 Aug (2)	11 Aug	15 Aug (2)	16 Aug	21 Aug	22 Aug (2)
Above Surface	16,500	22,000	19,000	33,000	19,000	19,000
0 m	11,000	20,000	16,500	19,000	16,500	16,500
Sediment-Water Interface	4,825	2,800	4,600	16,500	2,800	2,800

(2) indicates site 2

Table 10a. Sediment Composition (Weight %)* Upper 1 cm, Site 1, 1972

Particle size	9 Feb	10 Feb 1**	10 Feb 2	22 Mar 1	19 Apr 1	19 Apr 2	20 Apr 1	20 Apr 2
VC Sand	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00
C Sand	0.26	0.45	0.22	0.00	0.00	0.00	0.00	0.00
M Sand	2.07	0.45	0.53	0.44	0.00	0.00	0.00	0.60
F Sand	24.11	44.41	24.83	40.75	28.50	33.90	34.10	39.60
VF Sand	1.30	6.47	3.24	5.69	10.90	14.20	3.80	6.90
Silt-Clay	72.26	48.22	70.86	53.11	60.60	32.80	62.10	52.90

Particle size	7 May 1	9 May 1	9 May 2	9 May 3	9 May 4	9 May 5	9 May 6	9 May 7
VC Sand		0.00	0.00	0.00	0.00			
C Sand		0.00	0.00	0.00	0.00			
M Sand	77.10	0.00	0.00	0.00	0.00	84.30	79.70	70.10
F Sand		63.30	1.06	51.70	53.60			
VF Sand		23.60	66.04	23.60	14.30			
Silt-Clay	22.90	12.60	32.40	24.70	32.10	15.70	20.30	29.90

*based on the Wentworth scale (Wentworth 1922)
**indicates the core number

Table 10a. continued

Particle size	9 May 8	9 May 9	9 May 10	9 May 12	9 May 13	9 May 14	9 May 15	21 May 1
VC Sand		0.00	0.00	0.00	0.00	0.00	0.00	0.00
C Sand		0.00	0.00	0.00	0.00	0.00	0.00	0.00
M Sand	74.90	0.00	1.10	0.00	0.00	0.00	0.00	0.00
F Sand		63.00	58.90	44.90	49.80	59.90	44.81	52.37
VF Sand		18.30	21.80	14.80	16.30	9.00	24.99	32.73
Silt-Clay	25.10	18.70	17.20	40.30	34.10	31.10	30.20	29.14

Particle size	21 May 2	27 May 1	27 May 2	29 May 1	1 Jun 2	5 Jun 1	5 Jun 2	12 Jun 1
VC Sand	0.00	0.00			1.38	0.00		0.00
C Sand	0.00	0.00			0.00	0.00		0.00
M Sand	0.00	0.00	33.99	32.55	0.00	0.00	53.57	0.00
F Sand	78.35	53.90			55.52	39.51		51.81
VF Sand	6.75	9.78			15.58	18.64		13.37
Silt-Clay	14.90	36.32	66.01	67.45	27.52	44.67	46.43	34.82

Table 10a. continued

Particle size	20 Jun 1	20 Jun 2	22 Jun 1	22 Jun 2	22 Jun 3	22 Jun 4	22 Jun 5	22 Jun 6
VC Sand	0.00		0.00	0.00				0.00
C Sand	0.00		0.00	0.00				0.00
M Sand	0.00	49.97	0.00	0.00	84.63	48.27	66.95	0.00
F Sand	54.34		75.15	35.66				36.31
VF Sand	12.74		9.48	43.82				21.83
Silt-Clay	32.91	50.03	15.37	20.52	15.37	51.73	33.05	41.86

Particle size	26 Jun 1	26 Jun 2	12 Jul 1	12 Jul 2	20 Jul 1	20 Jul 2	11 Aug 1	16 Aug 1
VC Sand			0.00			0.00	0.00	0.00
C Sand			0.00			0.00	0.00	0.00
M Sand	32.19	33.95	0.00	67.20	69.67	0.00	0.00	0.00
F Sand			38.98			45.04	41.74	48.13
VF Sand			36.79			13.78	8.95	9.30
Silt-Clay	67.81	66.05	24.31	32.80	30.33	41.18	49.31	42.47

Table 10a. continued

Particle size	16 Aug 2
VC Sand	
C Sand	
M Sand	46.97
F Sand	
VF Sand	
Silt-Clay	53.03

Table 10b. Sediment Composition (weight %)* Upper 1 cm,

Particle size	17 Jul 1**	17 Jul 2	26 Jul 1	26 Jul 2
VC Sand		0.00		0.00
C Sand		0.00		0.00
M Sand	46.49	0.00	38.24	0.00
F Sand		64.64		30.74
VF Sand		9.15		8.84
Silt-Clay	53.51	26.21	61.76	60.42

*based on the Wentworth scale (Wentworth 1922)

**indicates core number

Site 2, 1972

15 Aug 1	15 Aug 2
0.00	
0.00	
0.00	58.64
38.46	
15.97	
45.57	41.36

Table 10c. Sediment Composition (Weight %)* Upper 4 cms, 1971-1972

Particle size	13 Jun 1971	17 Jul	12 Aug	13 Aug	25 Aug	26 Aug	27 Aug
VC Sand	0.00	1.04	0.00	0.53	0.00	1.39	1.53
C Sand	1.35	16.71	0.00	2.66	0.00	2.08	0.46
M Sand	41.15	52.74	0.00	47.94	7.53	10.41	7.76
F Sand	28.67	26.11	88.72	44.74	90.43	78.40	87.94
VF Sand	0.90	1.57	6.48	1.07	2.01	7.63	9.18
Silt-Clay	22.94	1.83	4.80	3.06	0.02	0.09	0.13

Particle size	27 May (1) 1972	29 May (1)	5 Jun (1)	12 Jun (1)	20 Jun (1)	26 Jun (1)	12 Jul (1)
VC Sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C Sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M Sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F Sand	70.55	59.76	67.11	68.59	72.24	73.24	72.36
VF Sand	15.68	7.43	13.92	5.92	8.77	3.18	19.93
Silt-Clay	13.76	32.81	18.97	25.49	48.99	23.58	7.71

*based on the Wentworth scale (Wentworth 1922)
(1) indicates site 1

Table 10c. continued

Particle size	20 Jul (1) 1972	24 Jul (1)	3 Aug (1)
VC Sand	0.00	0.00	0.60
C Sand	0.00	0.00	19.42
M Sand	0.00	0.00	13.17
F Sand	54.12	57.32	27.28
VF Sand	19.55	18.14	11.91
Silt-Clay	26.33	24.55	26.72

11 Aug (1)	16 Aug (1)	21 Aug (1)
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
53.30	53.55	47.67
6.50	24.97	26.99
40.19	21.48	25.38

Table 10d. Sediment Composition (Weight %),* Upper 4 cm, Site 2, 1972

Particle size	17 Jul	26 Jul	4 Aug	10 Aug	15 Aug
VC Sand	0.00	0.00	0.00	0.00	0.00
C Sand	0.00	0.00	0.00	0.00	0.00
M Sand	0.00	0.00	0.00	0.00	0.00
F Sand	67.19	62.71	32.87	64.95	50.30
VF Sand	18.52	6.01	26.93	4.55	0.00
Silt-Clay	14.39	31.28	40.20	30.50	49.70

*based on the Wentworth scale (Wentworth 1922)